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HUMAN FACTORS ENGINEERING ANALYTIC PROCESS DEFINITION AND CRITERION DEVELOPMENT FOR

Computer **A**ided **F**unction-allocation **E**valuation **S**ystem

JANUARY 1976

BOEING AEROSPACE COMPANY ● SEATTLE, WASHINGTON

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CAFES

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ABSTRACT

This report presents results of a study to: (1) develop descriptive information for the Human Factors Engineering process in system development; (2) evaluate the Computer Aided Function-Allocation Evaluation System (CAFES) for ability to support the process and for desirable refinements; and (3) define task and equipment data requirements for CAFES. In the resulting "single thread" description of an approach to performing HFE activities, the requirements, methodology and examples of a manual approach are presented. These are followed by brief descriptions of CAFES models and their capability to support the process. Candidate concepts for further refinement and application of CAFES are included.

KEY WORDS

Computer Aiding in Human Factors Engineering
Computer Aids to Crewstation Design
Crew Performance Evaluation
Crewstation Geometry Evaluation
Crew System Design
Digital Simulation
Function Allocation
Functional Flows
Human Operator Simulation
Human Performance Modeling
Man-Machine Function Allocation
Man-Machine Interface Development
Task Analysis
Timeline Analysis
Workload Analysis

-B-

FOREWORD

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1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

1.1.1 General

Objectives for this study effort were to develop and provide an explicit human factors engineering (HFE) analysis procedure that would apply in using the Computer Aided Function-allocation Evaluation (CAFES) computer models (Ref 19 through 28). These objectives also included the intent to refine the user interface definition for use of CAFES submodels, and to provide a concept for initiating storage of data in the data management system. The general approach for achieving the objectives was to:

- Refine the definition of the human factors engineering (HFE) analytic process, in order to refine related CAFES features for most effective application by the analyst
- Provide an initial definition of operator task data requirements, criterion considerations, and organization/listing for use with CAFES.
- Provide an initial definition of equipment data requirements, and concept organization/listing for use with CAFES.

Major elements of the approach followed to meet study objectives were to:

1. Summarize HFE objectives in system development programs.
2. Develop a description of an HFE analytic process that would satisfy the objectives, including
   a. Detailed description and examples for a baseline analytic process.
   b. Summary information on HFE methods and data requirements.
3. Summarize CAFES features, outputs and uses in supporting the baseline.
4. Identify correlated CAFES data requirements and desirable refinements to support the HFE process.

1.1.2 Background

Conditions leading to this study related to existing CAFES development status, the desire to initiate near term applications, and the need to define a specific HFE approach in order to better evaluate, refine and use the CAFES submodels. Current Development status provided the general capability to support an extremely wide range of potential user desires and applications. However, the overall scope, coverage and flexibility were so broad that it could be difficult for a new user to comprehend and effectively use CAFES during an initial exposure. Accordingly, it was desirable to develop an applications approach that could be used as an outline guide by an analyst in developing his efforts, and according to a concept that would be readily supported by the various CAFES submodels, i.e., the:

- DMS - Data Management System
- FAM - Functions Allocation Model
- WAM - Workload Analysis Model
- CAD - Computer Aided Design
- CGE - Crewstation Geometry Evaluation
- HOS - Human Operator Simulator

Several methodological and performance limitations related to the HFE state-of-art were instrumental in providing the impetus for this study. Some form of resolution was highly desirable in order for CAFES refinements and eventual applications to be most effective. First, the general methodological framework for Human Factors Developments and for CAFES had been identified and outlined in Military Specification MIL-H-46855, "Human Engineering Requirements for Military Systems, Equipment and Facilities." However applications experience has indicated a wide range of differences existed in interpretation, philosophies and approaches; technological gaps in approaches that are employed, and methods for bridging such gaps; and inconsistencies in both methodology and associated logic structure. Such differences inhibited most effective use of the computer aids. At a minimum, some interim resolution was required to provide an analytic procedure as well as to provide a framework to refine the CAFES aids for better support to the HFE analyst.

1.1.2 (Continued)

Most specifically, the requirement was that the analytic process selected as a concept for a system development program would precisely, clearly and systematically lead from one step to the next, and would provide a conceptual framework paralleling the desirable sequence of activities for most effective use of CAFES submodels.

Secondly, the HFE analyst in a new development program has often been confronted with a dilemma. On the one hand, effective support to system project needs is given high priority and requires sufficient flexibility, freedom and time to perform such studies as are required to be most immediately and fully responsive. On the other hand, there is a great deal of effort involved in deriving the comprehensive, time consuming analyses that could be involved for a major system development program. Frequency, much of this effort is redundant, such as from one aircraft system to the next (all aircraft take off, climb, descend, land, and all have many common operating requirements). In practice, the dilemma has been frequently resolved by taking a calculated risk based on judgement derived from professional experience. However, resulting effectiveness has varied. Alternatively, a preliminary concept for a baseline analysis reflecting common requirements could be developed and used for present purposes. A detailed expansion could later be stored for ready modification or updating to tailor the data to a specific system.

Third, it was uncertain as to how to best provide for the most effective user interface to enable his management and control of submodel elements. It was desirable that the analyst be efficiently and effectively kept in the CAFES loop without generating undue, detailed programmer-type activity leading to increased analytical workloads. This would include the analyst's involvement in: developing and maintaining an overall concept for the developing hardware system; reviewing, updating and monitoring "routine" information to detect problem areas and modify information as required; and having ready visibility and traceability for potentially critical problem areas in order to focus attention where needed to resolve such problems. It would also include provision for the analyst to develop new information as required, and readily incorporate data in the CAFES structure.

1.1.2 (Continued)

It was considered imperative that the analyst continually participate in task development and that his capabilities be optimally employed, so that the submodels provide the necessary details, organization and information to reflect the most effective application of his professional experience, judgment, skill, intuition and insight. Such expertise could be beneficially used when innovative solutions to difficult problems are needed. This essential and critical element of the user interface was to be retained in the automated organization, processing, integration and presentation of data in the user-CAFES interface operations.

Finally, the scope of potential overall HFE applications areas vs candidate requirements for input-output data and interpretation vs available data was known to be massive and complicated. Additionally, there are significant problems in determining and evaluating compatibility of human factors data. There was even a question as to whether data has to be compatible or comparable for intra-program operations; or whether it would be sufficient to inform the user/analyst of the required decision and available data, and then require him to take the appropriate action.

In attacking the overall scope and in making more appropriate decisions, use of HFE system analysis techniques has been demonstrated to provide for a systematic organization and integration of the morass of information, and to contribute an improved overall likelihood of success for the HFE process in a system development program. Basic elements of methodology that existed have been manually developed and correlated to provide a systematic step-by-step procession and correlation of system concepts, missions and functions through detailed task analysis, task timelines, workload and design-development evaluations. The need remained to clarify the rational elements within each method and the procedures to follow between steps in order to specify a progression most compatibile with both user and computer modeling requirements.

1.1.2 (Continued)

Accordingly, the overall intent for this study report has been to produce a baseline approach for HFE efforts that can be used in an initial resolution of the various analytic problem areas and requirements that have been indicated. This "single thread" manual approach was intended to provide a relatively standard procedure that could be readily applied as one concept for using CAFES.

While this report is not intended to develop a full blown hardware system development concept, it provides a sequence of applications and uses of the manual process in sufficient depth to be used as a guide in CAFES applications. It also develops and outlines the manual mode and concept sufficiently to support later detailing, revision, expansion and updating for a hardware system and for associated use of CAFES. An added desire for the approach to be outlined herein was an attempt to retain adequate flexibility in the approach in order to enhance individual preferences and methods.

However, the most important overall objective was to establish a framework for using CAFES, for refining the CAFES concept and submodels to enhance utility, and for initiating storage of data. This resulting general approach was to:

- Lay out a more formalized approach for HFE processes outlined in MIL-H-46855 in order to reflect a relatively precise and systematic methodology/model for developing the analyses.
- Postulate the approach for a specific system (an aircraft) to which CAFES might be applied in future efforts. (Since it has been estimated that over 80% of functional requirements are common between aircraft, more detailed development of this initial approach would lead to a reasonably stable base for future use and would readily transition to a specific aircraft concept for early CAFES applications refinements.)
- Evaluate the approach adopted in terms of: (a) implications for most beneficial CAFES submodel refinements, and (b) reverse implications of CAFES on the HFE approach.

1.1.2 (Continued)

- o Determine user interface implications and desirable refinements to enhance overall utility of the submodels. Include consideration of the desirability for the analyst to manage and use pre-programmed information by review and exception, or by expansion and modification. Also consider data concept, input-processing, output operations, and interpretation.
- o Develop an initial data concept and organization-storage scheme for incorporating data in the CAFES Data Management System according to a standard format.

1.2 SUMMARY

This report covers four major areas relating to HFE requirements, methods, use of CAFES, and data needs. It provides:

- o Summaries of the HFE role and responsibilities in a system development program
- o Development of a pragmatic methodology for performing HFE tasks in a system development program
- o Relationships of CAFES submodels and operations to the methodology
- o Outline of task and equipment data needs to accomplish the above.

Human factors engineering objectives include philosophy, concepts for an overall system development approach and the typical HFE task flow. These are correlated with specific task and activity requirements imposed by the defense Systems Acquisition Review Council and by specification as well as necessary integrations of operator performance variables. The scope of coverage is demonstrated to be so large as to require an extremely systematic approach for comprehensive coverage, integration and detailed development of such information.

A baseline process methodology is developed and presented to reflect an approach to performing a systematic progress of task activities in HFE efforts for system development. The methodology employed outlines the approach to be taken, relates the steps in the approach, and provides for developing the systematic and integrated progression of HFE activities to assure that sufficient levels of detail to cover all potential areas of examination have been included. Examples of each portion of the developed methodology are carried to enough detail to provide the human factors analyst with guidance in application of the methodology, and in the selection, preparation, use, and interpretation of results when using CAFES submodels. The approach is tailored toward use in Naval Weapons Systems development but it should be remembered that the methodology and CAFES submodels have wider applicability. The methodology appears to be applicable to non-weapons sytems development (e.g., command and control; air traffice control) in addition to providing an indication of training, manning, and procedures requirements for each system.

1.2 (Continued)

Data system requirements to support the process are identified. An information system concept was determined to be necessary, whether the process was produced by manual or computer aided methods. Task - equipment data requirements and criterion considerations are indicated.

CAFES relationships to the baseline HFE process are identified. This is accomplished by providing an overall summary of CAFES, including characteristics, outputs and uses. A concept summary is provided for each submodel as appropriate, and submodel system requirements specifications are included to reflect a summary of submodel objectives and features. Similarly, submodels incorporated in CAFES are correlated with the baseline process, and particular data needs are highlighted.

2.0 TECHNICAL REPORT

2.1 HUMAN FACTORS ENGINEERING OBJECTIVES

The task activities performed by a Human Factors Engineering Analyst during a system development cycle are many and varied, and are constantly changing in scope and definition. The following treatise on an Analytic Process Definition and Criteria Development is an attempt to initiate a concept for an integrated and comprehensive methodological approach-that can use both manual and computer methods to provide timely and relevant Human Factors inputs to a weapons system development. The treatise is by no means an entirely original concept. Background material, information and experience from many sources and knowledgeable individuals have been gathered and synthesized to form the integrated approach to be presented.

2.1.1 General Human Factors Engineering (HFE) Role

The Systems Development Process encompasses those activities necessary to conceive, define, design and acquire a system capable of performing the desired activities within specified limits of acceptability. HFE activities are part of this definition and acquisition cycle since people are an integral part of the systems. System operators or crewmen are included primarily because of their information processing capability, their decision making capability, their ability to generate small forces at proper times (i.e., control movements, switch actuations, etc.) as controlling functions for implementation of subsystem activities.

The entire systems development activity of the Human Factors Engineering analyst is dedicated to optimizing the capabilities of the man-machine combination. This task is to effect maximum information processing and control in system operations, within the required time and accuracy constraints, and to provide the human operator with the interface for determining and effecting necessary changes in operation. Fullest achievement requires analysis and confirmation of man-machine interface provisions for <u>all</u> subsystem activities, as such activities fluctuate in normal operations or in degraded operations throughout the system mission.

2.1.1 (Continued)

Accordingly, and during a system development, HFE technology is responsible for organizing information and performing trade-offs to define and allocate functions to man and equipment, and for defining: control-display requirements, station layout and arrangement, provisions for effective crew operations and performance, workload capability, and crew environment/life support requirements. Another element of data applications is in providing task-equipment inputs for training and procedural considerations.

In turn, large quantities of pertinent information are generated during the development of a weapons system. Over a period of time much of the data is lost, and only limited amounts reach a publication which may be subsequently recovered by interested parties. More extensive recording and availability of such information would have long term benefits, particularly in early stages of a new system development. The development of a new weapons system would be greatly enhanced by accessibility to historical data on previously examined weapons systems. For example, baseline Functional Flow Block Diagrams could provide a wealth of information applicable to all generic weapons systems developments, properly and formally constructed and recorded to a level of indenture to allow individual task identification and function action-information requirements. More specifically, mission phases and functions for aircraft operation are sufficiently common to allow extensive carry-over from one weapon system development to another. Individual subsystem implementation modes and components will have variations (e.g., single engine-multi engine) but the same <u>function</u> will be performed and must be satisfied in each phase of operation, e.g., Pre-Flight, Taxi, Take-off, Climb, Cruise, etc. The deviations may be readily identified by the human factors analyst and specific requirements and provisions for task activities adjusted accordingly.

However, the scope of information, areas of concern and interactive elements are such that methodology, in addition to being applicable to the question at hand, must be manageable in both time and manpower requirements. The techniques outlined by the methodology must be geared to providing pragmatic solutions to the problem at hand, based on the information available at the present time. Applications must also be capable of utilizing existing data,

2.1.1 (Continued)

be capable of updating as new information becomes available, and be available to all interested in utilizing this information. The solutions offered must also be capable of being modified and improved as new or additional information becomes available.

Developing a data storage system based on such a philosophy and using a functional flow concept to develop a range of similar baselines for generic weapons systems developments (e.g., aircraft, ships, command-control-communications systems) will enhance the capabilities of the human factors engineer to rapidly and effectively establish design information for a future development of new systems. The groundwork for establishing most of the preliminary information required for workload analyses and function allocation, as well as selection of the equipment with which the man interfaces, can be built up over a period of time— the information developed on one weapons system can be stored for recall, sorting and use during development of subsequent systems, or for use as applicable to other types of systems. This stored record, tempered by the judgment and experience of the human factors analyst, can provide many timely answers to systems designers. Thereby, initial original designs and configurations may incorporate desirable human factors refinements before system concepts or physical structure become fixed.

2.1.2 General Human Factors Engineering (HFE) Responsibilities and Requirements

During initiation of a typical system development program, the HFE specialist is tasked to help translate a set of general operational requirements into specific concepts and requirements for system development. His role is to assure that human performance and support requirements are identified and properly provided for, at any level of system control, operation and maintenance. Additionally, he must identify and help resolve any significant technological questions or data gaps that will impact the development program and resulting mission effectiveness.

Accordingly, the scope of the HFE role ranges from early concept definition and trade-offs (to avoid undue assumptions concerning subtle human factors elements) through detail design and development. Throughout a program, the specialist must ensure that candidate human performances and support requirements with corresponding capabilities and limitations are properly identified, traded-off and implemented. General objectives are to appropriately provide for the most effective contribution of human performance to mission success, and to avoid undue mission limitations or constraints from the human element in the system.

In application, ability to perform all the HFE tasks most effectively has been limited. Each new system features a distinct set of parameters that can significantly impact human performance and support requirements. Effective performance of the tasks requires a comprehensive knowledge and integration of system mission and functional requirements, with control-display state-of-art and related human performance capabilities, limitations and constraints. While many parameters will be familiar and routine, alternative applications can significantly change the operator framework and new applications concepts can pose totally new problems. While major areas of concern can typically be identified rather readily, the detailed analysis and integration of all parameters to cover subtle variations with significant effects is cumbersome, time consuming and tedious. The level of detail that may be required (particularly for routine and familiar concepts) is objectionable to most analysts, with a most frequent complaint being that they are "re-inventing the wheel" in performing comprehensive analyses.

2.1.2 (Continued)

On the other hand, even very early system development needs may require detailed information and long range developmental/operations forecasting by the HFE analyst in order to avoid eventual system mission limitations, constraints or retrofits because of human factor limitations. Timing, scope and foresight of the HFE specialist thus become critical in this process. Even in early conceptual phases of system development, he must complete a preliminary effort that includes (1) appraise the mission, (2) determine the system functions, (3) assess the resulting crew functions, tasks and task elements, (4) trade whether most effective performance would be by man or machine, (5) identify crew task features and associated crew capabilities and limitations, (6) develop probable control-display requirements, features and candidates, (7) define and perform individual capability trades for controls, displays, crew interface features, and crew performance, (8) conceive an effective crew station layout concept, (9) evaluate the resulting configuration for effective integrated performance of all tasks, and (10) confirm crew workload conditions and procedures/training requirements. As is readily obvious, the HFE time required can become extensive, the process is iterative throughout system development, and continuing review is required to reappraise preceding decisions in context with developing hardware features. Concurrently, more detailed levels of system definition emerge and associated HFE studies progress with corresponding increments in levels of detail.

In performing the HFE role, three sets of requirements apply. One is the necessary information to be developed for the Defense Systems Acquisition Review Council (DSARC) and the four phases involved (Table 2.1-1). Second is the detail requirements for HFE efforts as outlined in MIL-H-46855 (abstracted in Table 2.1-2). Third is the scope of operator performance variables, capabilities, limitations and constraints to be considered in trade-offs by the HFE (a top level summary is presented in Table 2.1-3; detailed considerations, constraints and data ramifications expand dramatically from this level).

TABLE 2.1-1

SUMMARY OF HUMAN FACTORS ENGINEERING REQUIREMENTS AND RESPONSIBILITIES IN A DEVELOPMENT PROGRAM

Development Phase	Human Engineering Responsibilities	Input Requirements	Outputs
PRE-DSARC*			
General Operational Requirement (GOR)	1) Identify potential HF 2) Develop gross performance criteria 3) Assess relevant HF data availability	1) Gross op. requirements 2) Technology forecasts 3) Alternate des./op	1) Potential HF problem definition 2) Performance/operating criteria
Tentative Specific Operational Requirement (TSOR)	1) Analyze critical HF problems 2) Analyze mission functions/tasks 3) Preliminary man/machine (M/M) allocation 4) Estimate system HF efforts 5) Identify critical interface problems 6) Develop initial approaches for alternate concepts	1) Outputs from GOR phase 2) System time/cost constraints 3) Alternate des./op concepts 4) Empirical performance data	1) Gross mission scenario 2) Function flow chart 3) M/M task allocation 4) Man/machine interface definition 5) Recommended technical approaches
Proposed Technical Approaches (PTA)	1) Develop detailed mission scenario 2) Perform m/m tradeoff studies 3) Perform preliminary operability maintain/analysis 4) Develop design optimization 5) Define explicit operating concept 6) Select technical approach and develop HF test plan	1) Outputs from TSOR phase 2) Hardware/software/op. 3) Mission requirements 4) Select design characteristics 5) Empirical performance data	1) Performance goals/ requirements 2) Operator/maintenance skill requirements 3) HF concepts and data for PTA preparation 4) Tech. approach and test plan
Specific Operational Requirement (SOR) or Advanced Development Objective (ADO)	1) Prepare detail HE test plan 2) Update previous HE analysis 3) Develop operator station 4) Conduct trades and prepare specs 5) Perform operability and maintainability analysis	1) Outputs from PTA 2) Subsystem interface requirements 3) Design optimization trades 4) Cost/schedule estimates 5) Empirical data	1) Operability and maintainability goals 2) Detailed HE plans 3) Expanded station design concept 4) HE system specs
Technical Development Plan (TDP)	1) Define m/m allocation criteria and revise allocation and info flows 2) Develop operational sequencing diagrams 3) Refine HE data and define HE technical program 4) Develop RFP work statements, system specs and proposal evaluation criteria	1) Outputs from SOR or ADO 2) Revised requirements, design concepts and m/m allocation 3) Results of trade studies and system tests 4) Empirical data	1) Revised data and concepts 2) Initial RFP work statement, system spec, etc. 3) Major problem area 4) HE technical program plan description
DSARC I			
Request for Proposal (RFP) Preparation	1) Analyze problem areas identified in RFP 2) Integrate HE contributions to prel. design of baseline configuration 3) Update all HE outputs and empirical data 4) Expand functional analysis and allocation to final level 5) Finalize RFP statement of work	1) Outputs from TDP 2) Specific hardware requirements and costs 3) Human perf. requirements 4) Updated design, layout and plans 5) Empirical data	1) Finalized RFP SOW to be issued to contract

*DSARC - Defense Systems Acquisition Review Council

TABLE 2.1-1 (Continued)

Development Phase	Human Engineering Responsibilities	Input Requirements	Outputs
Proposal Evaluation	1) Evaluate contractor proposals in terms of adequacy of: a) Understanding of the role of HE relative to overall system b) Soundness of approach c) Design tradeoff parameters d) Proposed solutions to special HE problems e) Mockup, development and utilization f) Test and evaluation plans and methodologies 2) Identify critical areas not noted by contractors	Same as above plus outputs from RFP	Written reports of each task
DSARC II			
Prototype Development, Evaluation and First Flight	1) Participate in detail designs for aircraft and subsystems and support and training equipment 2) Perform tests to verify man/machine performance/procedures 3) Monitor detail engineering changes and note problems 4) Develop plans and procedures for training 5) Evaluate and review progress reports 6) Inspect and evaluate prototype 7) Identify special problems and coordinate with contractor for optimum solutions 8) Conduct laboratory, ground simulation and flight tests to evaluate HE performance (e.g., time and motion, work load, job aids, m/m interface) 9) Participate in development of detail plans for first flight 10) Redefine operability and maintainability goals 11) Test and evaluate maintenance and training equipment and procedures 12) Develop recommendations for improved system design and operational procedures	Varying according to types of component models used	1) Mockup demonstration data 2) HE design specification document 3) Detailed design layout or work station and equipment performance specifications 4) Detail plans for flight test, training and operation 5) Specific recommendations for design and procedure improvements 6) Updated HE technical manuals 7) Training and maintenance manuals
Deployment Evaluation	1) Identify and evaluate operational deficiencies 2) Propose new technology feasibilities 3) Update data bank and replace previous estimates with operational data 4) Revise technical training and maintenance manuals	Vary according to types of component models used	1) Finalized operational, design, training and maintenance documents and manuals 2) Updated HE technical program specifications and operational data
DSARC III			
Production	1) Ensure production unit comply with contract	Same as above	Written reports of each task

TABLE 2.1-2

OUTLINE OF MIL-H-46855

3.1 General Requirements
- 3.1.1 Scope and Nature of Work
  - o Analysis
  - o Design/Development
  - o Test and Evaluation
- 3.1.2 Human Engineering Program Plan and Other Data
  - 3.1.2.1 Human Engineering Program Plan
  - 3.1.2.2 Changes to the Human Engineering Program Plan
  - 3.1.2.3 Other Data
- 3.1.3 Non Duplication (of Effort)

3.2 Detail Requirements
- 3.2.1 Analysis
  - 3.2.1.1 Defining and Allocating System Functions
    - 3.2.1.1.1 Information Flow and Processing Analysis
    - 3.2.1.1.2 Estimates of Potential Operator/Maintainer Processing Capabilities
    - 3.2.1.1.3 Allocation of Functions
  - 3.2.1.2 Equipment Identification
  - 3.2.1.3 Analysis of Tasks
    - 3.2.1.3.1 Gross Analysis of Tasks, Involving/Providing
      - 1. Determine System Performance Can Be Provided by Proposed Personnel-Equipment Capabilities
      - 2. Assure Human Performance Requirements Do Not Exceed Human Capabilities
      - 3. Input Data for
        - o Preliminary Manning Levels
        - o Equipment Procedures
        - o Skill/Training Requirements
        - o Communication Requirements
      - 4. Critical Human Performance
      - 5. Possible Unsafe Practices
      - 6. Promising Improvements in Operating Efficiency
    - 3.2.1.3.2 Analysis of Critical Tasks
      - 1. Identifying
        - o Information Required by Man, Including Task Initiation Cues
        - o Information Available to Man
        - o Evaluation Process
        - o Decision Reached After Evaluation
        - o Action Taken
        - o Body Movements Required by Action
        - o Workspace Envelope Required by Action
        - o Workspace Available
        - o Location/Condition of Work Environment
        - o Frequency/Tolerances for Action
        - o Time Base
        - o Feedback on Action Adequacy
        - o Tools and Equipment Required
        - o Number of Personnel Required and Specialties/Experience
        - o Job Aids/References Required
        - o Special Hazards Involved
        - o Operation Interaction Where More Than One Crewman is Involved
        - o Operational Limits of Man (Performance)
        - o Operational Limits of Machine (State-of-the-Art)
      - 2. Covering All Affected Mission/Phases, Including Degraded Modes of Operation
    - 3.2.1.3.3 Loading Analysis
      - 1. Individual Crew Member Workload Analysis Compared with Performance Criteria
      - 2. Crew Workload Analysis Compared With Performance Criteria
  - 3.2.1.4 Preliminary System and Subsystem Design

TABLE 2.1-2 (Continued)

3.2.2 Human Engineering Studies, Experiments and Laboratory Tests

3.2.2.1 Studies, Experiments and Laboratory Tests

3.2.2.1.1 Mockups and Models

3.2.2.1.2 Dynamic Simulation

3.2.2.2 Equipment Detail Design Drawings

3.2.2.3 Work Environment, Crew Stations and Facilities Design

- o Atmospheric Conditions
- o Weather and Climate
- o Range of Accelerative Forces
- o Acoustic Noise, Vibration and Impact Forces
- o Provision for Human Performance During Weightlessness
- o Provision for Minimizing Disorientation
- o Space for Crew, Activity and Equipment
- o Physical, Visual and Auditory Links for All Man-Equipment Interfaces
- o Safe, Efficient Walkways, Stairways, Platforms, Inclines
- o Provision to Minimize Psychophysiological Stresses
- o Provision to Minimize Fatigue - Physical, Emotional, Work-Rest Cycle
- o Effects of Clothing, Personal Equipment
- o Equipment Handling Provisions, Including Remote Handling and Tools
- o Protection from Hazards - Chemical, Biological, Toxicological, Radiological, Electrical, Electromagnetic
- o Optimum Illumination Per Visual Tasks
- o Sustenance, Storage and Sanitation
- o Crew Safety Protection Relative to Mission Phase and Control-Display Tasks

3.2.2.4 Human Engineering in Performance and Design Specifications

3.2.3 Equipment Procedure Development

3.2.4 Human Engineering Test and Evaluation

3.2.4.1 Planning

3.2.4.2 Implementation (Include As Applicable)

- o Simulation or Actual Conduct of Mission/Work Cycle
- o Human Participation Critical to Speed, Accuracy, Reliability, Cost
- o Representative Sample of Non Critical Scheduled/Unscheduled Maintenance Tasks
- o Proposed Job Aides
- o Use of Representative User Personnel, Clothing and Equipment
- o Task Performance Data Collection
- o Task Performance Discrepancies - Required vs Obtained
- o Criteria for Acceptable Performance

3.2.4.3 Failure Analysis (Human Error Factors)

3.2.5 Cognizance and Coordination (Interdisciplinary Integration)

3.3 Data Requirements Per Contract Data List

3.4 Data Availability to Procuring Activity

3.5 Drawing Approval by HFE for Man-Machine Interfaces

TABLE 2.1-3: REPRESENTATIVE OPERATOR PERFORMANCE VARIABLES

Human Factors Interface (Information-Control Factors)	PERFORMANCE FACTORS/CONSIDERATIONS/TRADE-OFFS (CAPABILITIES/LIMITATIONS/CONSTRAINTS)		
Data Sensing Modes **(Display Modes-Vision; Audition, Tactile; Musclèposition/Kinesthesis, Smell)**	Access/Display Location Functional Requirements/ Grouping Sensor-Function/Capability Type/Intensity of Signal Discrete/Continuous/ Intermittent Signal Accuracy Reaction Type/Time	Logic Diagrams Pattern/Trend Information Display Correlation Display Symbology Methods Display Clutter Feed Back on Status/Change Static/Dynamic Cueing Direction of Movement Cues Coding/Size/Shape/Color	Reliability Criticality/ Error Impact Resolution/ Sensitivity Fatigue/Alert-ness Trainability Other
Decision/Judgment Factors **(Data Interpretation-Processing/ Integration/Diagnosis/Prediction)**	Type/Number of Steps Extent of Integration Extent/Type of Diagnosis Problem Complexity Procedures Complexity Display-Control Correlation	Communication Requirements Conflicting Factors Ambiguity in Data "Set"/Expectancy Display Emphasis Stress/Criticality	Knowledge/ Familiarity Memory Retention Habits Trainability Other
Control Operation Factors **(Manual/Motor Capability and Skills)**	Access/Control Location Functional Requirements/ Grouping Reaction Type/Time/Rate Force/Distance/Direction Discrete/Continuous/ Intermittent Actions	Correlated Displays Correlated Actions Operations Sequence/ Frequency/Criticality Logic Diagrams Coding(Designation/Size/ Shade) Procedures	Reliability Error Impact Skill Completion Dexterity/Retention Trainability Other
Work Space Envelope **(Station Layout/Human Anthropometry/Mobility Required)**	Display-Control -Arrangement/Functional Grouping (Position Correlation) -Access/Reach	Motion Links/Constraints/ Time Procedural Interrelations Workspace Size/Layout	Other
Environmental **(General Impact on Performance/ Physiology)**	Lighting Temperature Humidity	Airflow Fatigue/Alertness Noise	Emergencies Operating Stress/ Constraints
General **(Overall Effects/Constraints)**	Priorities Stress Time Constraints	Operations Criteria -Qualitative -Quantitative	Workload Safety Standards State-of-Art Tradition/Acceptance

2.1.2 (Continued)

In practice, achieving all HFE requirement and objectives has been a massive and complex job. There has been no generally accepted and applied standardized approach, nor has there been any precise and systematic definition of the processes involved. HFE approaches have been highly individualized and heavily dependent on professional experience, skill and judgment. Initially individuals used the approach that best suited their own needs as required, to define and maintain an overall system concept, to identify and track relatively routine areas of development, and to identify and resolve unique or critical problem areas. Unfortunately, the record demonstrates that many areas were overlooked. Use of the more intuitive, individualized approach became even less satisfactory with the advent of increasingly complex systems.

HFE system analysis techniques were developed to provide a more systematic progression of methods that would enhance quality, impact and thoroughness of technical effort. Analytic methods that evolved parallel the requirements of MIL-H-46855 in supporting system development from early concept formulation through detailed analysis and critique of task performance requirements, capabilities and workload. However, applications of many of the methods are still in the evolutionary stage, and there has been inadequate development and correlation of information in the sequence of methodological steps, so that outputs from one step are not yet clearly defined inputs for the next. More systematic applications remained heavily a function of individual expertise and judgment: in skipping steps, in using intuition and insight, and in "optimizing" the risks accepted in making short cuts. Redundancy between systems still carried some of the notion of "re-inventing the wheel" and a tendency to avoid some elements as unnecessary. Unfortunately there remained a corresponding risk of overlooking key data elements, of ignoring an unfamiliar problem area, or of failing to perceive the implications of a new context for traditional or routine systems and equipment concepts.

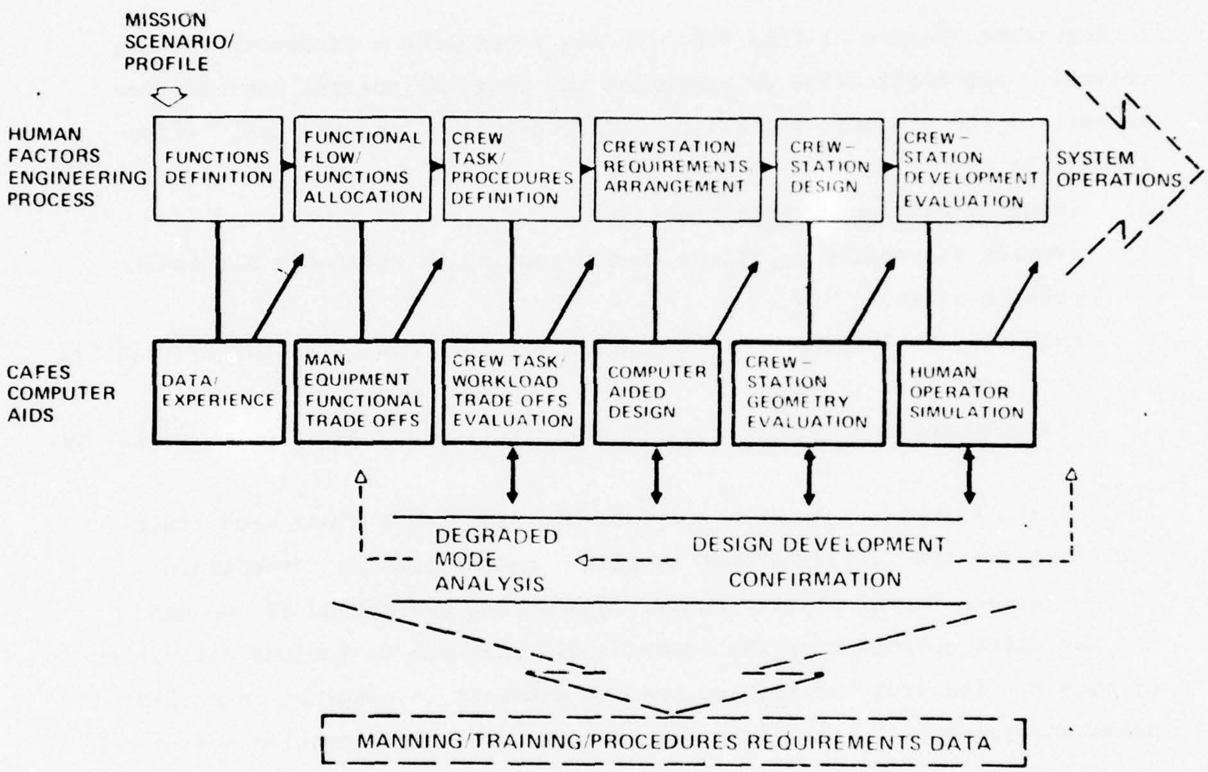
In summary, the basic approach sequence for HFE requirements is outlined in MIL-H-46855. However, applications have lacked in consistent utilization of a precisely defined and systematic procedure. In turn, computer modeling

has been somewhat constrained by the absence of logical, quantifiable steps in procedure; and submodel development has been more general purpose than desirable in concept, in order to suit alternative approaches. On the other hand, if an approach were adopted, developed and stored to offer information rapidly, and with little or no effort by the analyst, it would very likely be used extensively.

The Computer Aided Function-Allocation Evaluation System (CAFES) is a computerized design tool being developed to assist the human factors engineering analyst in system development programs. Basic features are summarized in Table 2.1-4, reflecting both a correlation with many of the requirements of MIL-H-46855 and capabilities for resolving some of the problems described in earlier text. CAFES is a crew systems design support tool based on human engineering methods, computer aids, human performance data, and data management needs. It is intended to support crew systems engineers in system development efforts, including man-machine research, requirements analysis, design, test, training, and maintenance systems development. Principle advantages are that: it can be applied extremely early in concept development to retrieve, structure and use available information, it can continue to be used as a developmental tool and as a recording system for on-going project efforts, and it can expedite.

Considerable potential for CAFES refinement to reduce system development workload for the analyst was considered to exist if a manual methodological concept were to be devised that could satisfy all the hardware system program, specification and technological requirements indicated earlier. By establishing an appropriate analytic baseline for both manual methods and for application of CAFES computer models, much of the manual organization of concepts and data could be pre-constructed and stored in the CAFES framework. Accordingly, the analyst could avoid excessive involvement in detailed concept structuring or programming type operations. Instead, he could use and manage the pre-stored data by exception or by refinement and expansion. Accordingly, it would be easier to use the pre-structured baseline as a "spring off" for added developments, than to become heavily involved in organizing relatively routine concepts and data.

TABLE 2.1-4: CAFES ELEMENTS APPLIED TO WEAPON SYSTEM DEVELOPMENT



2.1.2 (Continued)

The present study was thus to develop a baseline approach for HFE analysis that would support all requirements, provide an initial concept for a future system, and provide a reference model for identifying candidate CAFES refinements. An essential element was to identify concepts that could enhance CAFES use and interpretation, including assistance in spotting problem areas in providing solutions, and evaluating effectiveness of the solutions.

An important feature of this approach was to provide a framework for the retention and application of essential and critical analyst capabilities as part of the process, so that he could understand and use CAFES effectively to:

- o Identify critical system problems.
- o Provide innovative solutions to non-routine or extremely difficult problem areas.
- o Evaluate the implications of model operations and data quality relative to the problem at hand.
- o Off load routine data retrieval, organization and calculation functions.

Basic CAFES structure provides considerable assistance along such lines. The intent of the "single thread baseline" concept was to establish a bridge between representative manual methods and operations on one hand and the CAFES submodels on the other hand. This was to include definition of more routine programmable and tedious elements in contrast to analyst needs and capabilities as an evaluator, decision maker, problem solver and innovator.

2.2 ANALYTICAL PROCESS DEVELOPMENT

Evolution of a baseline process methodology for HFE activities has been in developmental stages for many years. This is the set of activities, and the sequence of events, which are undertaken by the human factors analyst during a system development cycle. A number of approaches have been developed as each of the HFE activity elements has been examined, changed, altered, added to, excluded, given different emphasis, resurrected under different titles and had format and content altered. Throughout this evolutionary process (which is still going on) there has been an evolution of a more consistent set of definitions, a general agreement on the ordering of the elements and a general agreement on the definition of the elements.

Production of a baseline human factors engineering methodology with intended use of the CAFES submodels as an integral part is a unique undertaking. The processes and techniques involved in CAFES are not new but in the past have required manual efforts of such duration as to frequently render the results more of a verification of previous decisions than a design tool to be used during the development of the weapons system. The use of computer computational speed and capacity to support the process in CAFES provides for quick, accurate data retrieval, organization and calculations, and also the storage and processing capacity necessary for a newer analytic mode -- to begin comparison to alternate solutions within an early time frame compatible with the weapons system development needs. Producing initial weapon system mission functional flow definitions will still be laborious and time consuming, but because of redundancy and commonality between systems (e.g., between aircraft) can be used indefinitely. It is only necessary that new system elements or unique mission related functional requirements will require definition for a new application of a weapon system. Analysis and comparison of alternate functions allocations and refinements anywhere in the analytic structure will be readily and quickly accomplished in CAFES, and presentation methods are available for the analyst to comprehend and interpret data, implications and results.

2.2 (Continued)

Development of a baseline process has required re-examination of candidate HFE activity elements related methodological concepts and their relationship with Computer Aided Function-Allocation Evaluation Systems (CAFES) submodels. The submodels are designed to do the routine data retrieval, organization and calculations necessary to support the analytic process, by acquiring and helping to apply useful, comprehensive, comparative and absolute data. These data processes and calculations are needed from early functions allocations through detailed evaluation of physical and visual compatibilities of crew and crew station configurations, task sequencing, detailed task allocation between man and machine, task allocation among crew members, crew workloads and effectiveness of a given task set vs mission requirements.

2.2.1 Baseline Process

More general but typical areas of HFE activity during a system development cycle are illustrated in Figure 2.2-1. This figure provides a summary of the types of efforts and expected inputs. A summary concept for the overall flow of HFE task processes is shown in Figure 2.2-2. This figure summarizes the internal working relationship for HFE tasks and illustrates directly or by implication the interelationship of these tasks with hardware, software, manning, training and procedures activities.

The specific Baseline Process "single thread" Methodology sequence adopted for purpose of the present study is diagrammed in Figure 2.2-3. The approach outlined identifies both specific HFE efforts and their sequencing, for a system development program carried out from early concept formulation on through the design and development process. Subsequent discussion in this section on Analytic Process Development expands on the approach by providing summary descriptions, by outlining any particular restraints or ground rules for application, and by providing examples as appropriate. This approach provides for developing the information that was required by the system acquisition requirements that were summarized in Table 2.1-1. It is structured in such a way that the analyst can adopt and follow the methodology usefully, early in a program, can retrieve and organize such information as exists and is recorded in a meaningful, useable format, and can initiate an analytic process that can be used through system development.

2.2.1.1 Operational Requirements/Mission Profile

The general system operational requirements are an evolving composite of requirements starting with the General Operational Requirement (GOR) and progressing through the Specific Operational Requirements (SOR) as was illustrated in Table 2.2-1. The operational requirements define the system for developmental consideration and outline the limits of operations necessary for the fulfilling of the weapons system mission activities. During the progressive evolution of the system, iterative updates and expansions are incorporated from various analysis, evaluation, production and user groups. A detailed and complete definition of system operational

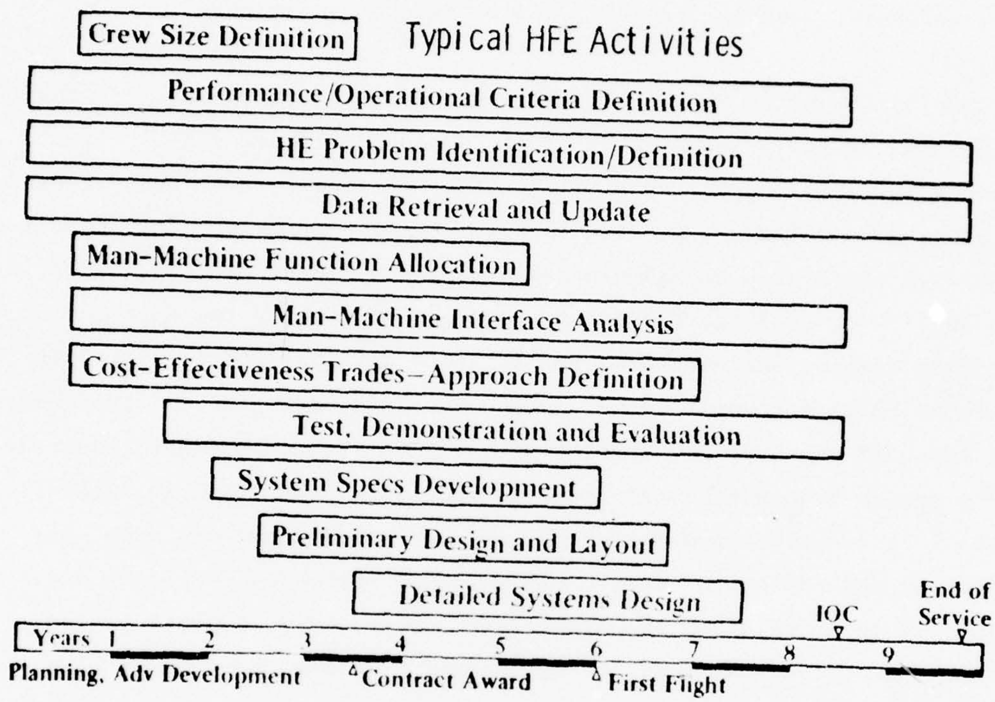


FIGURE 2.2-1: SYSTEM DEVELOPMENT CYCLE- HFE ACTIVITY AND SUPPORT AREAS

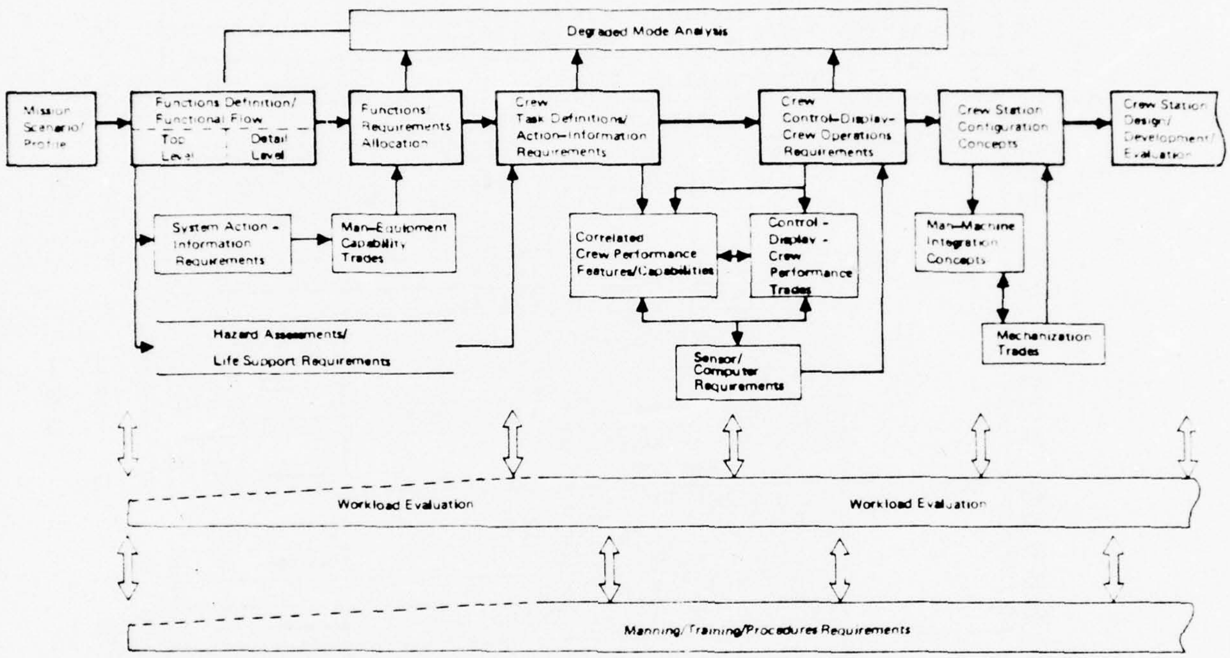


FIGURE 2.2-2: SUMMARY HFE TASK FLOW

No.	Activity		Feedback
1	SYSTEM OPERATIONAL REQUIREMENTS/MISSION PROFILE		
2	MISSION SCENARIO/GROSS TIMELINE		
3	FUNCTIONAL FLOW BLOCK DIAGRAMS		
4	FIRST LEVEL		
5	SECOND LEVEL		
6	THIRD LEVEL		
7	LOWER LEVEL		
8	FUNCTIONAL ACTION - INFORMATION REQUIREMENTS		
9	CANDIDATE CONTROL - DISPLAY EQUIPMENTS		
10	HUMAN FACTORS REVIEW	→ TO	2
11	CREW-EQUIPMENT FUNCTIONS ALLOCATION (FAM)		
12	TASK TIMELINES / GROSS DEFINITIONS / OPERATIONAL SEQUENCE DIAGRAMS		
13	INTRA CREW TASKS		
14	CREW SIZE, SKILL TASK ALLOCATION		
15	CREW TASK - WORKLOAD ANALYSIS (WAM)		
16	TASK FEASIBILITY APPRAISAL		
17	CREW -EQUIPMENT REVIEW	→ TO	2
18	DEGRADED MODE EVALUATION	→ TO	1 2 3
19	CRITICAL TASK ANALYSIS	→ TO	1 8 13
20	CRITICAL CONSTRAINT ANALYSIS	→ TO	1 8 13
21	WORKLOAD - CONTRAINTS - DATA REVIEW	→ TO	8 13
22	CREW STATION DEVELOPMENT (CAD)		
23	EQUIPMENT TRADE STUDIES		
24	DESIGN - CONSTRAINTS	→ TO	2
25	CONFIGURATION CONCEPTS		
26	GROSS CREWSTATION EVALUATION	→ TO	11 12
27	CONFIGURATION REVIEW	→ TO	21
28	DETAILED CREW STATION EVALUATION		
29	OPERATIONAL REQUIREMENTS COMPLIANCE		
30	SYSTEM COMPLIANCE AND PERFORMANCE REVIEW	→ TO	10
31	ALTERNATIVE APPROACH TRADE-OFF ANALYSES	→ As Req'd	
32	DESIGN SUPPORT DATA COMPILATION		
33	MANNING, TRAINING, PROCEDURES DATA	→ As Req'd	

FIGURE 2.2-3 HFE PROCESS FOR PRESENT BASELINE CONCEPT

2.2.1.1 (Continued)

requirements provide the judgemental criteria by which elements of the weapons system may be compared and evaluated for mission suscces probabilities.

Even initial general requirements will include such features as the types of activities to be performed, the duration of each activity required, physical characteristics necessary to satisfy system functions to be performed, and perhaps the desirabie crew complement to perform the necessary functions. Initial HFE task activity will include identification of any human factors problem areas and general performance-operating considerations, requirements and crtieria. As the concept definition evolves, such activity will become similarly more definitive.

During early definition of operational requirements and associated operational descriptions, an initial mission profile (such as is illustrated for aircraft in Figure 2.2-4) can be constructed to graphically depict major requirements in the form functional elements in the profile. Each functional element (or functional requirement) describes a segment of the mission. Each segment is self-contained, that is, it has a clearly distinguishable start-to-complete operation, setting the stage for subsequent indentured breakdown for more detailed functional requirements.

2.2.1.2 Mission Scenario/Gross Timeline

Mission Scenario

The Mission Scenario is developed from the mission profiel and operational requirements. In narrative form, the Mission Scenario verbally describes the events which make up the full mission or segments of the mission, summarizing typical operations, assumptions, mission environment and mission events that might occur. Key events in normal and degraded operations are identified and explained in an operational context to ensure that all requirements can be identified and are examined during the course of the evaluation. The scenario provides the source of information needed to confirm understanding of desired system operations,

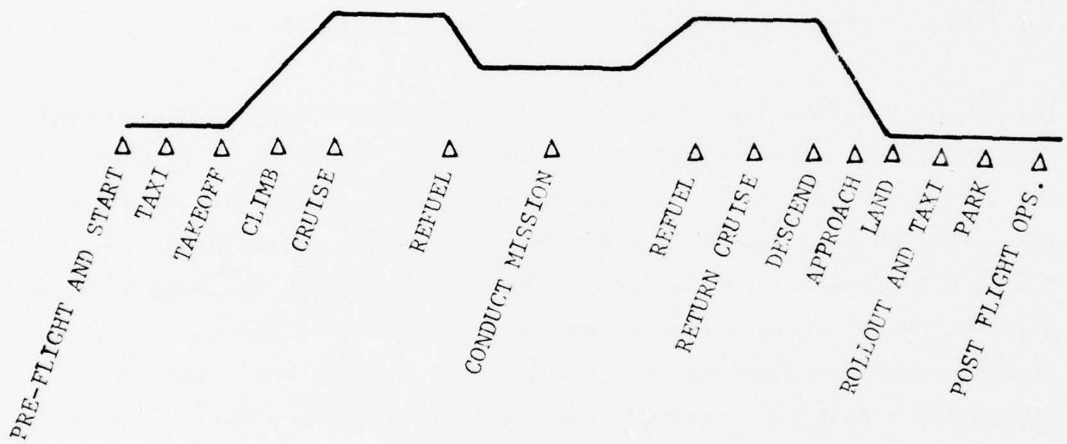


FIGURE 2.2-4: GENERAL MISSION PROFILE, AIRCRAFT

2.2.1.2 (Continued)

to detail system functions, action and information requirements, and to develop a detailed functional flow.

The scenario is one of the many critical segments in the early definition of weapons systems requirements. Because the scenario reflects integration of operational requirements, it is the initial source of information to establish such system elements and constraints as are related to crew size, crew functions, and equipment candidates. All decisions throughout development will ultimately refer back to the initial requirements definition and scenario to resolve any conflicts of judgement or equipment selection and use.

Elements of the scenario must, at a minimum, be sufficiently detailed to convey a comprehensive understanding of the mission, and to permit a break out of variations relating to such features as (1) the phases of the mission, (2) the type of activity performed in each phase, (3) the degree of accuracy, (4) any interdependencies of activities as to timing, information transfer, etc., and (5) the functions allocated to specific types of hardware, to a crewman or to a combination of the man and a subsystem.

Scenario narrative usually is capable of providing the above information. The narrative form often provides more information that is necessary for subsequent analytic steps, but it does assist in establishing an implied boundary to the scope of mission concept and operations which may or may not be established by the operating requirements or design specifications. The provision of a narrative scenario also provides an early opportunity for re-evaluation of mission concepts and definitions to ensure system mission, objectives and requirements are clearly defined and described.

The following example of a narrative scenario (modified from reference 43) is included in this section to provide both an illustrative example and a basis for examining the Functional Flow Block Diagrams which may be generated from the scenario. As will be evident, it would take very little

2.2.1.2 (Continued)

additional information to incorporate and fully describe detailed criteria and capabilities of all systems, including operating constraints and key failure modes.

Scenario Example: VFA-V/STOL Aircraft, Close Air Support

Sea Control Ship - 81 (SCS-81) is on station 160 miles Southwest of the battle area. At a pre-dawn briefing VFA-V/STOL squadron pilots are informed that major ground offensives are to be initiated at daybreak. It is anticipated that Close Air Support (CAS) will be required and two of SCS-81's VFA-V/STOL's have been configured for this mission; anti-personnel and armor piercing munitions have been loaded, the modular CAS peculiar avionics have been installed, and all auxiliary CAS software has been loaded. Routine briefing information is exchanged-including weather, anticipated defenses, modes and codes of the day, departure and battle area communication frequencies, and launch times. The two-man flight has been designated Yankee Flight. Detailed pre-flight inspections had been completed earlier and the pilots quickly move to their aircraft and start engines. System checks are run while that equipment requiring initialization is brought on line. The first VFA-V/STOL is spotted, launch clearance is obtained and a short takeoff (STO) is executed. Figure 2.2-5 depicts the mission graphically and Table 2.1-5 contains the mission segments, or phases.

Yankee Leaker takes off, retracts gear and flaps and begins transition to completely conventional flight. A quick glance at his emergency/warning multi-purpose display re-assures him that all systems are functioning properly. He begins a climbing turn to the selected inland heading and visually spotting his wingman begins accelerating to maximum endurance airspeed and altitude. He notes on his horizontal situation display the electronically generated way points and check points superimposed over the projected map presentation. Switching UHF frequencies, Yankee Leader contacts the Direct Air Support Center for his specific assignment and enroute clearance. He and his wingman are assigned to Airborne Forward Air Controller-Alpha (FAC(A)-Alpha) and are given a vector to Alpha from their coast checkpoint. The outbound cruise is routine. The passive threat detection and warning system is very quiet; the radar is placed in standby, and the prominent coastal checkpoint will be acquired either visually or electro-optically.

At dawn the ground feature check point is detected and confirmed by sensors at an extended range. Yankee Leader raises Forward Air Controller-Alpha FAC(A)-Alpha on the pre-assigned secure communication channel and receives his specific mission assignment and a more complete briefing. FAC(A) informs Yankee Flight that an advance enemy force has moved up during the night and will soon be within striking distance of a strategic friendly position. The enemy force consists of many troops, light armored vehicles, and rocket launchers. Recent experience has indicated that the enemy will also be equipped with advanced capability portable infrared

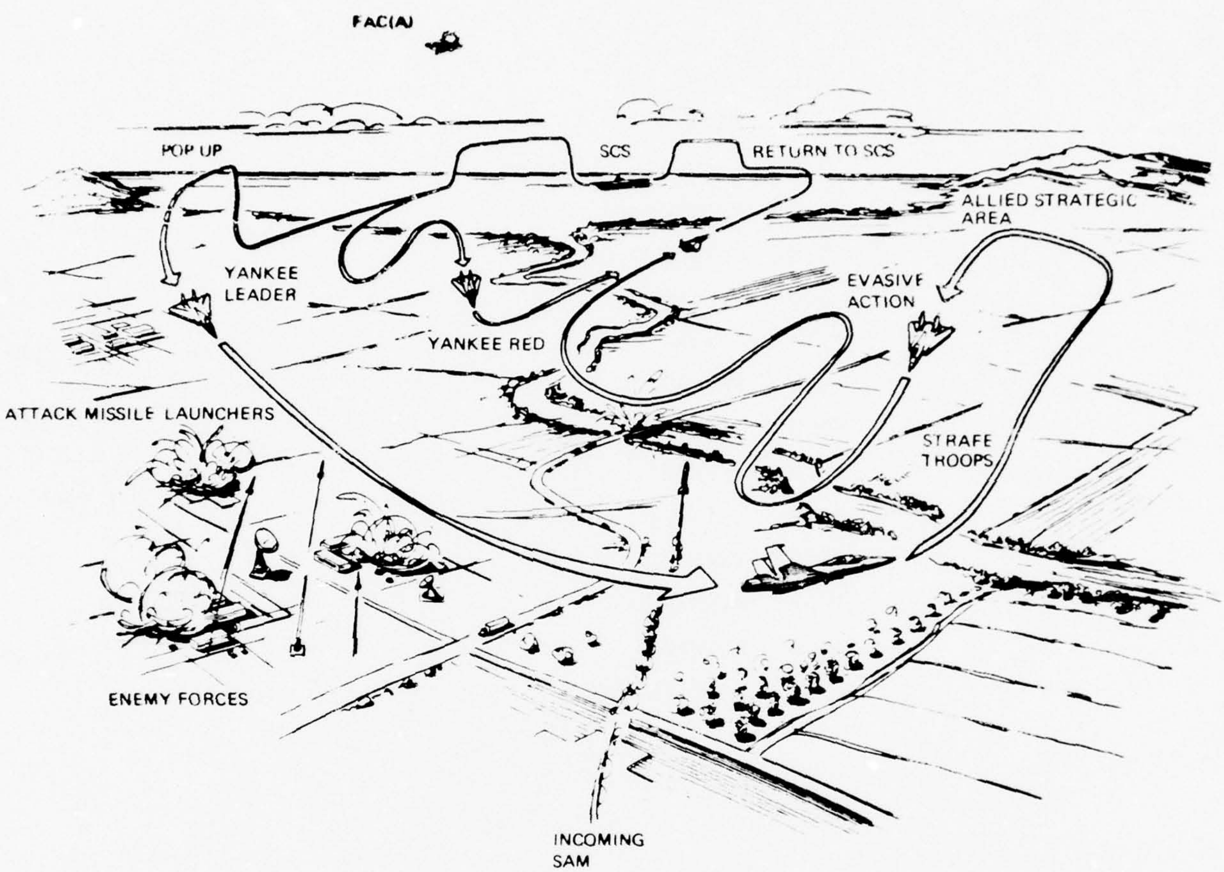


FIGURE 2.2-5: CLOSE AIR SUPPORT MISSION PHASES - PICTORIAL SCENARIO

TABLE 2.1-5 CLOSE AIR SUPPORT - FUNCTIONAL MISSION PHASES

1.0	PRE-FLIGHT
2.0	LAUNCH
3.0	CLIMB TO ALTITUDE
4.0	RENDEZVOUS
5.0	OUTBOUND CRUISE
6.0	DESCENT
7.0	LOITER
8.0	PRE-ATTACK
9.0	ATTACK
10.0	ESCAPE
11.0	CLIMB TO ALTITUDE
12.0	INBOUND CRUISE
13.0	RENDEZVOUS
14.0	RECOVER
15.0	POST FLIGHT

2.2.1.2 (Continued)

Scenario (Continued)

homing missiles. There is no enemy air support. Preparations are underway for defense against the imminent attack. FAC(A)-Alpha provides an updated vector from the coastal checkpoint and assigns Yankee Flight a loiter position. Yankee Leader provides an estimated time of arrival (ETA) and crossing the coastline performs a navigation update, reduces power, and drops to a terrain following altitude. The penetration route has been chosen to minimize detection. No known enemy radar sites are along the route. There are no rockets indicated by the threat detection and warning set. Anticipating his upcoming strikes, Yankee Leaker reviews his ordnance load.

Reaching the loiter point, Yankee Flight re-establishes contact with FAC(A)-Alpha for update and target information. Alpha reports that friendly troops are presently pinned down under enemy rocket and mortar shelling. Strikes against enemy artillery could force it to seek cover which would allow friendly ground troops to move up. FAC(A)-Alpha and Yankee Flight establish visual contact and the FAC(A) reports that he will transmit coordinates of the enemy position. Since the weather is excellent and the attack will be executed visually, Yankee Leader selects a tactical presentation and selects the air-to-ground mode on his electronic displays. Also, since the enemy is still removed from the friendly forces, Yankee Leader decides on a low-level approach, pop-up, and rocket attack. In order to take maximum advantage of a possible suprise element, Yankee Red will execute the same attack from a different heading. Yankee Leader designates the reference coordinates on his tactical display for steering commands; due to the relatively flat terrain he selects a narrow field of view (NFOV) for the display on the Vertical Situation Display (VSD). Verifying and arming his ordnance selection, he coordinates with Yankee Red and initiates his low-level, high speed dash. Maintaining a precise heading, Yankee Leader detects his target several miles out and makes minor steering corrections. He pops-up, enters the dive, tracks his targets and launches his ordnance. FAC(A)-Alpha confirms that his attack has eliminated two of the enemy rocket launchers. Yankee Red has equal success a few seconds later. Circling high above the battle area, FAC(A)-Alpha reports that the remaining rocket launchers are moving to what little cover there is, while ground troops and many small vehicles are advancing.

Yankee Leader and FAC(A)-Alpha, in conjunction with the FAC(G) (Forward Air Controller-Ground), decide upon additional, low level strikes utilizing the aircraft cannon. Yankee Leader's break-off has removed him from the immediate battle area but the coordinates for the rocket attack were precise and he can accurately and quickly return to the battle area. He selects the guns to be employed. With the element of suprise gone, Yankee Leader is primarily concerned with encountering the infrared missiles. After coordinating with FAC(A)-Alpha and Yankee Red, Yankee Leader initiates his return to the battle. Slewing the high resolution sensor to designated reference points on his tactical display, Yankee Leader can begin a preliminary search of the target area before visually acquiring it. Assuming that any mobile missiles are confined to the immediate battle

2.2.1.2 (Continued)

Scenario (Continued)

area, Yankee Leader climbs to a better search altitude and reduces airspeed somewhat. He monitors his threat detection and warning information carefully. While slewing the sensor the pilot detects some small vehicular traffic. Yankee Leader increases power and heads directly along the bearing to these targets. Still searching with his sensor, he notes what appears to be troop activity and makes the necessary steering adjustments. Not completely sure of the activity he has detected he requests (FAC(G) to mark the forward edge of the friendly position. Sweeping the appropriate sensor in the direction he believes to be toward the friendly forces he detects the "mark" returns and confirms his orientation of the battle area. He is now positive that the activity he had detected is indeed the enemy advancement. Yankee Leader drops to a lower altitude and attempts to transition to visual operations. Flying directly toward the enemy line Yankee Leader visually acquires the intended target area. He verifies that guns are selected and notes the number of rounds still available. He trains his sight on the intended target area. When he confirms that it is in-range he begins a series of short bursts along the enemy forward line. Detecting a prominent ground flash, he immediately assumes infrared missile launch, breaks off his attack and takes advantage of his craft's unique maneuvering capability to avoid the missile.

Climbing to a safer altitude, he sees Yankee Red completing his attack. Both Yankee Leader and Yankee Red turn for one more attack run. Following this strike the friendly forces take advantage of the temporary confusion and disorganization to launch a counter-offensive and the engagement becomes too confined to allow any further air support. FAC(A)-Alpha releases the strike aircraft and informs the Direct Air Support Center (DASC) which releases Yankee Flight for a return to ship. Yankee Flight departs on the pre-established heading, air-speed and altitude.

Yankee Leader suddenly receives and confirms a threat warning, that he is being illuminated by a tracking radar. Displayed information indicates the source of the illumination and a recommended action. He performs countermeasure operations and makes a quick visual search for a possible missile launch or even an in-flight missile. He sees nothing. He receives a higher priority warning that the emitter is closing. Since Yankee Leader cannot see the missile, he instinctively rolls into a very sharp break-off. Pulling out at low altitude, he finds that he has broken track and elects to dash to the coast at terrain following altitude. Feet wet, Yankee Flight climbs to a greater altitude, selects local air control frequency, and activates homing aids for the return to ship. SCS-81 Combat Information Center contacts Yankee Flight and reports that CIC is tracking them on radar. Avionics are selectively shut down, vertical take-off/landing mode is selected on the primary flight display, and transition to vertical flight is accomplished. Yankee Leader executes a vertical landing, taxis, and shuts down.

2.2.1.2 (Continued)

Gross Timeline

A gross timeline for the various mission phases can be established at this point. Inspection of the mission profile will identify selected mission elements (e.g., take-off) for which time constraints can be estimated. The scenario provides additional time related information from which estimates or actual time constraints as imposed by the mission can be determined. With such information, both the general mission profile (Figure 2.2-4) and the pictorial scenario (Figure 2.2-5) can be adjusted to reflect time constraints.

The resulting gross time line is illustrated in Figure 2.2-6. Refining of timeline information will be a somewhat iterative process, to maintain current information on both absolute and inflexible time constraints and to establish and maintain time budget estimates and constraints as relevant to the various mission phases.

2.2.1.3 *Functional Flow Block Diagrams*

Functional flows, in block diagram format, are developed from the mission profile. These flows are system level and nonspecific, i.e., they are aircraft system and function oriented to define functional requirements for operations that have to be performed, and without distinguishing how they are to be performed or distinguishing man or equipment features. Examples of top level flows are presented in Figure 2.2-7, illustrating the segmented nature of the flows, with clearly distinguishable self-contained functions. Each of the top level, main functions, incorporates similarly self-contained and diagrammable subfunctions. These are reflected appropriately in flow diagrams which also reflect successive levels of indenture, or can be reflected in an outline format. The next level of indenture for representing overall mission functions/operations are shown in Figure 2.2-8, and more detailed levels for representative pre-flight activities are illustrated in Table 2.1-6. Another approach for both the profile and functions analysis for representative landing operations that are applicable to all aircraft (i.e., commun functions) is presented in Figures 2.2-9, 2.2-10 and 2.2-11. Still another, more

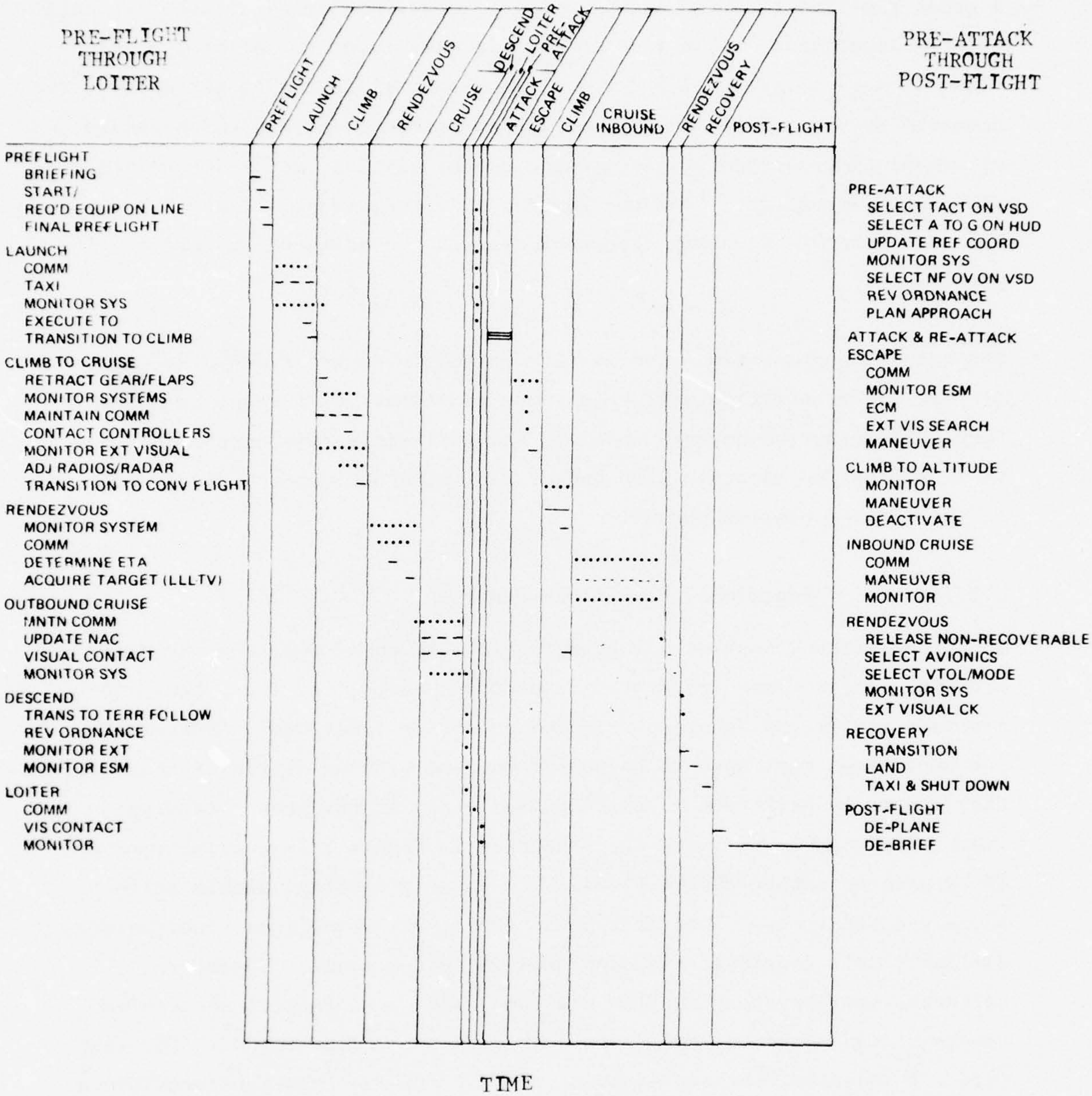


FIGURE 2.2-6: GROSS MISSION TIME LINES

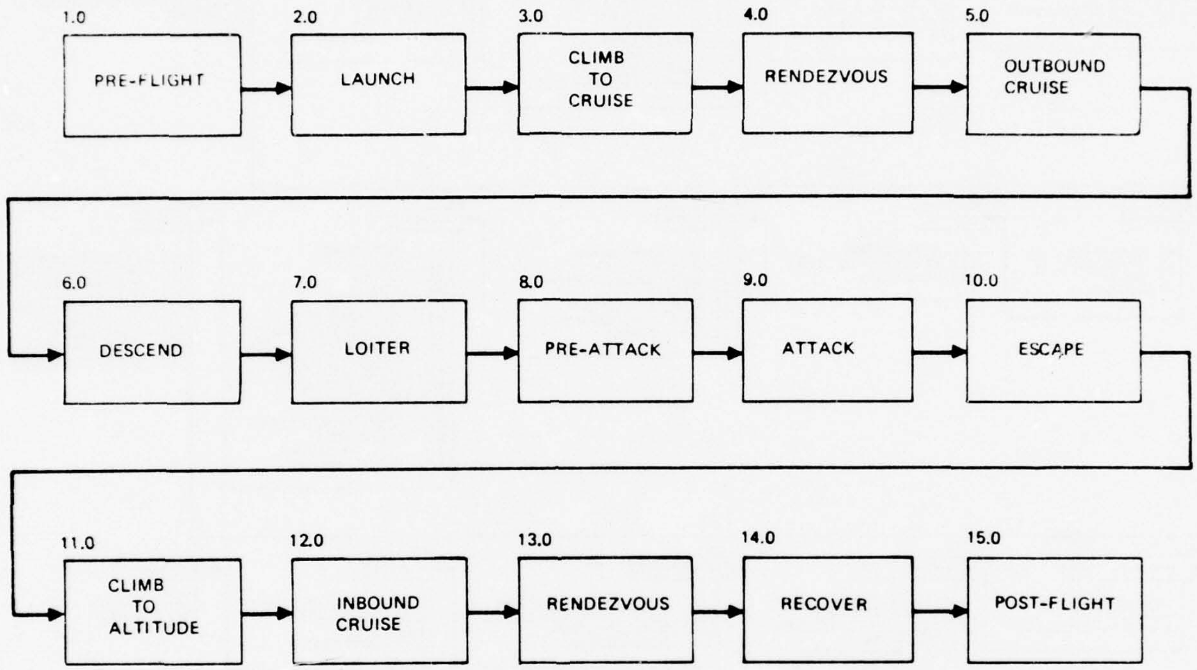


FIGURE 2.2-7: TOP LEVEL FUNCTIONSL FLOW DIAGRAM - CLOSE AIR SUPPORT

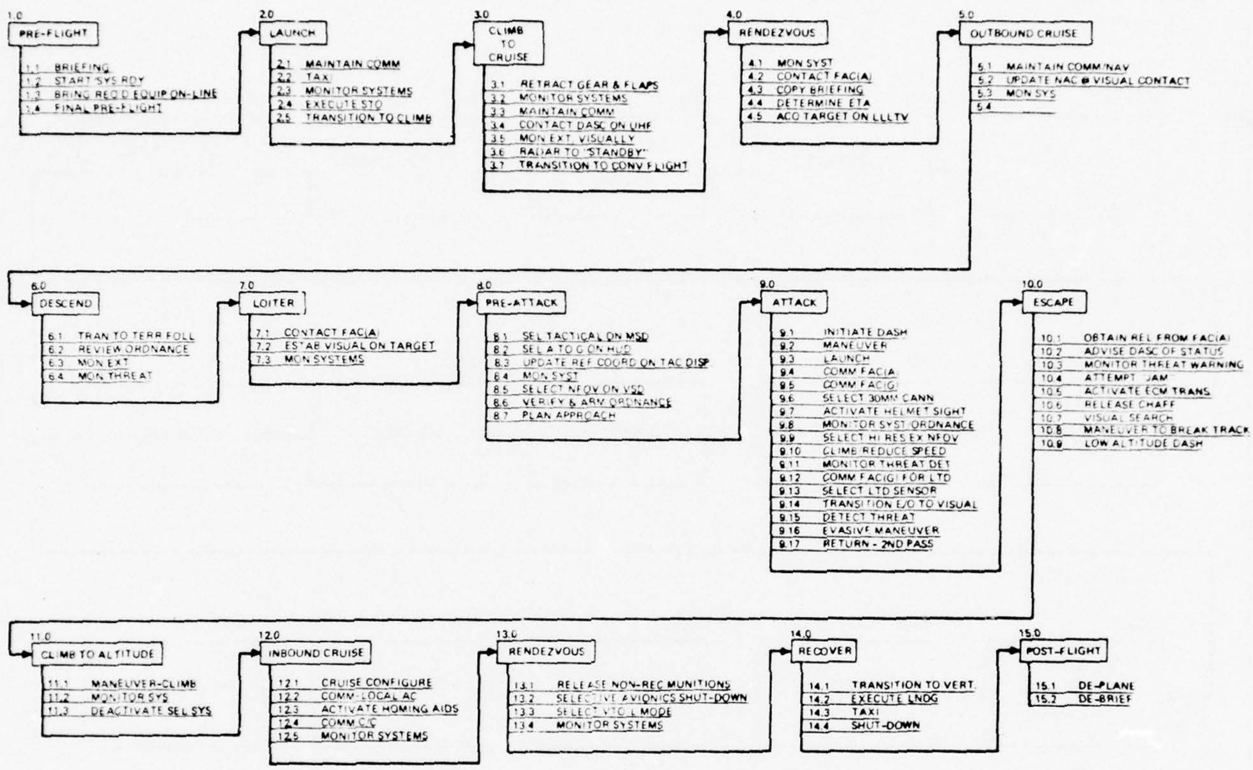


FIGURE 2.2-8: SECOND LEVEL CAS MISSION FUNCTIONS

TABLE 2.1-6

REPRESENTATIVE FUNCTIONAL FLOW INDENTURES - PREFLIGHT

1.0 PREFLIGHT

1.1 Briefing

1.1.1 Notate Briefing Data

1.1.2 Assemble Flight Aids

1.1.2.1 Flight Plan

1.1.2.2 Maps

1.1.2.3 Navigation and Communications Aids

1.2 Start Preflight Activities

1.2.1 Acquire Crew Station

1.2.1.1 Acquire Connectors

1.2.1.1.1 Life Support

1.2.1.1.2 Communications

1.2.1.1.3 Restraints

1.2.2 Acquire System Status

1.2.2.1 Vehicle Subsystems

1.2.2.1.1 Fuel

1.2.2.1.2 Hydraulic

1.2.2.1.3 Electrical

1.2.2.1.4 Fire Control

1.2.2.1.5 Propulsion

1.2.2.2 Survival Subsystems

1.2.2.2.1 Environmental Control

1.2.2.2.2 Oxygen

1.2.2.2.3 Emergency Supplies

1.2.2.3 Command and Control

1.2.2.3.1 Radios

1.2.2.3.2 Navigation

1.2.2.3.3 Displays

1.2.2.4 Weapons

1.2.2.4.1 Stores Complement

1.2.2.4.2 Status

TABLE 2.1-6 (Continued)

1.3 Bring Required Equipment on Line

- 1.3.1 Acquire System Readiness
  - 1.3.1.1 Activate Vehicle Subsystems
    - 1.3.1.1.1 Propulsion
    - 1.3.1.1.2 Electrical
    - 1.3.1.1.3 Fuel
    - 1.3.1.1.4 Hydraulic
    - 1.3.1.1.5 Fire Control
    - 1.3.1.1.6 Environmental Control
    - 1.3.1.1.7 Life Support
    - 1.3.1.1.8 Communications
    - 1.3.1.1.9 Navigation
    - 1.3.1.1.10 Additional Displays

1.4 Final Pre-Flight

- 1.4.1 Verify Vehicle and Crew Status
  - 1.4.1.1 Monitor Vehicle Subsystems
    - 1.4.1.1.1 Warning Displays
  - 1.4.1.2 Verify External Readiness
    - 1.4.1.2.1 Ground Control Clearance
    - 1.4.1.2.2 External Vehicle Restraint
    - 1.4.1.2.3 Ground Crew Readiness

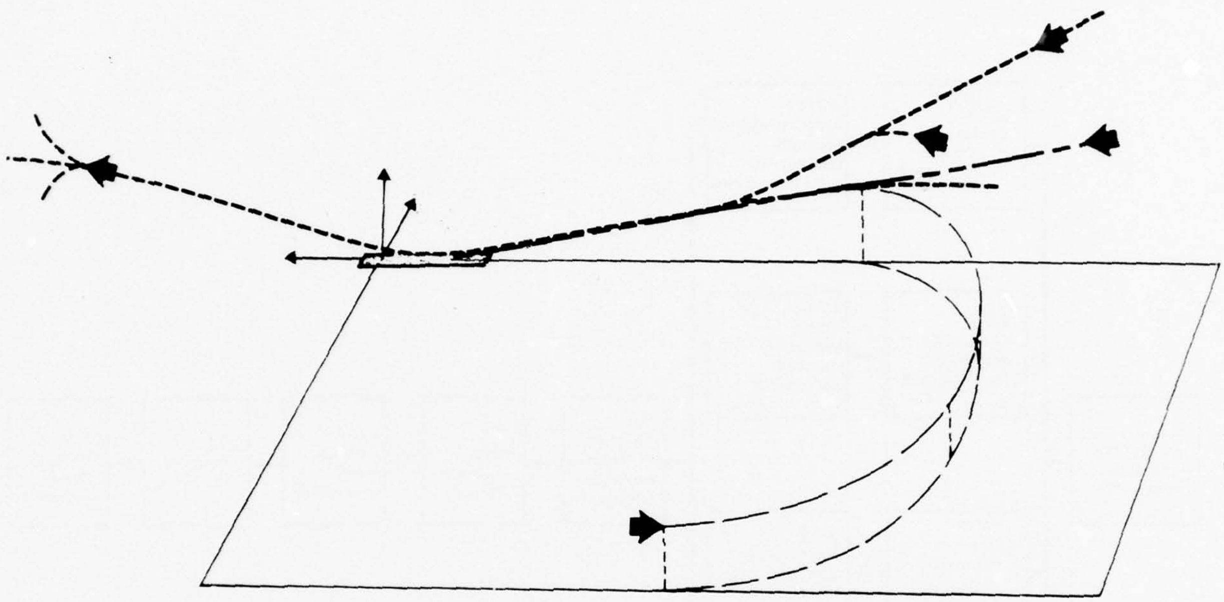


FIGURE 2.2-9: TERMINAL AREA OPERATIONS - REPRESENTATIVE APPROACH/GO-AROUND CONDITIONS

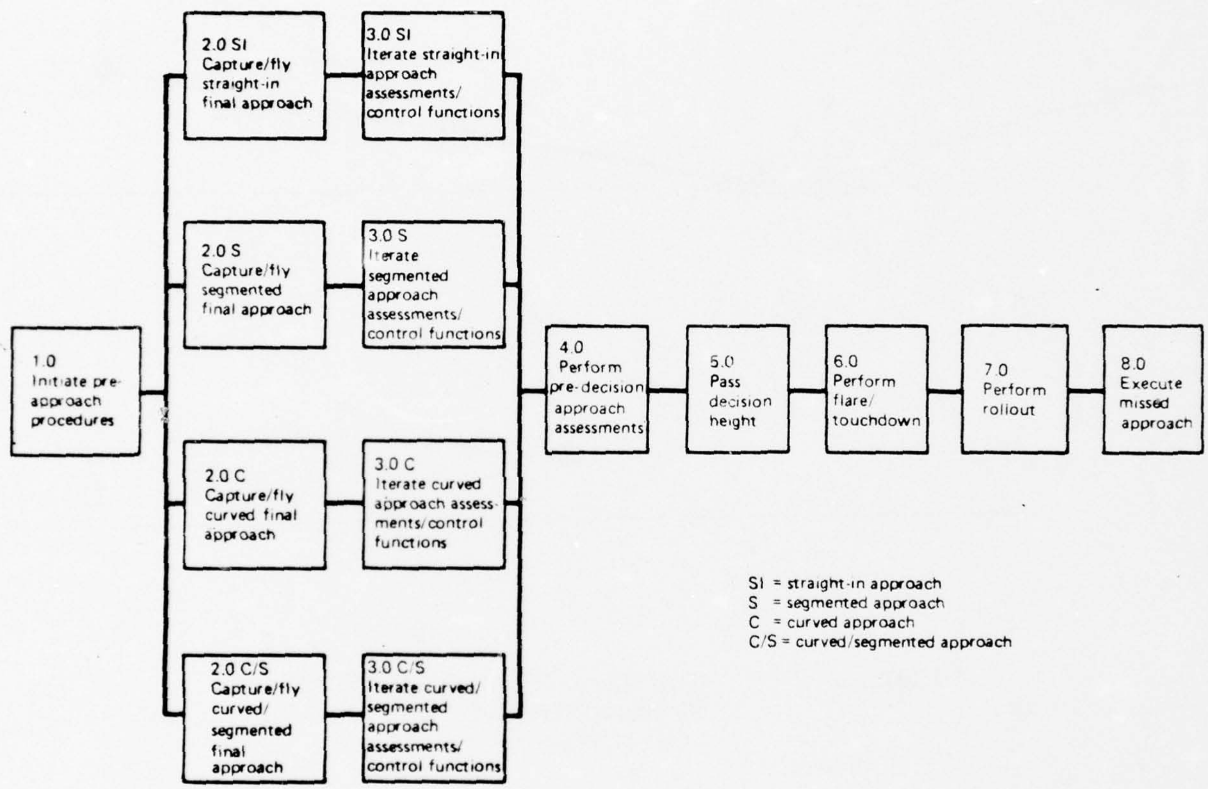


FIGURE 2.2-10: APPROACH/LAND SEQUENCE - FUNCTIONAL FLOWS FOR FOUR APPROACH PROFILES

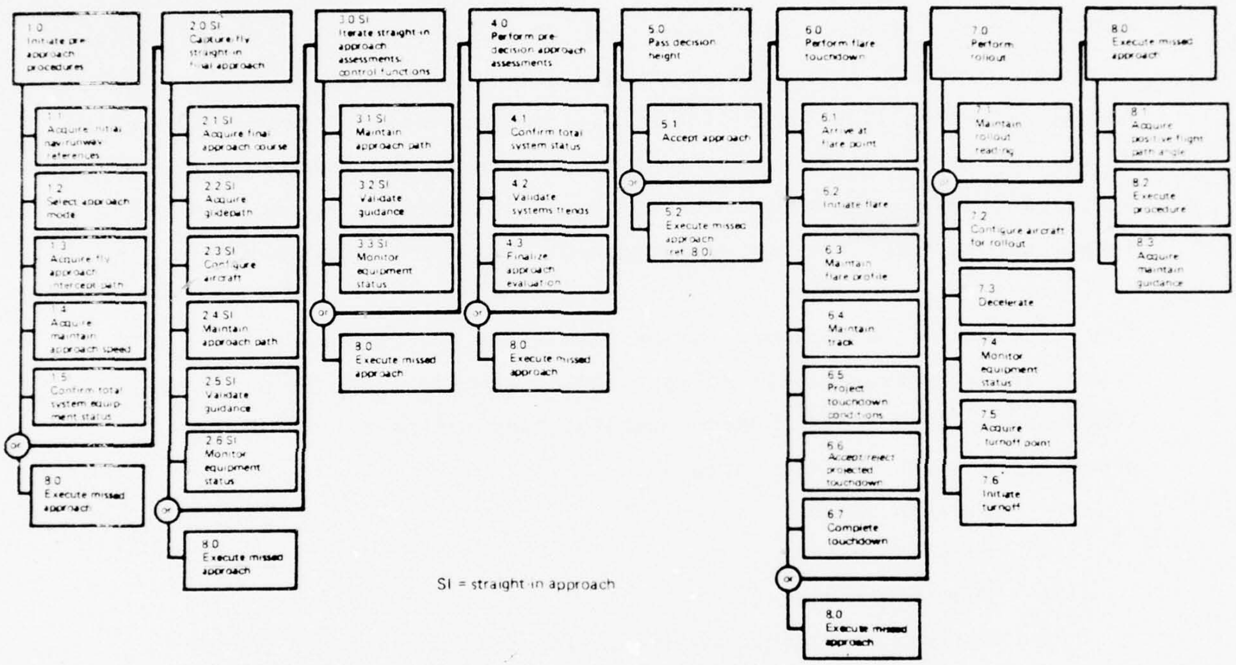


FIGURE 2.2-11: APPROACH/LAND - NEXT LEVEL FUNCTIONAL FLOWS FOR STRAIGHT-IN APPROACH

basic approach with broader utility, that might be applied to improve flexibility is shown in Figure 2.2-12 and Table 2.1-7, reflecting summary information for function-action-information indentures for a possible refueling operation in event the CAS mission is modified to include refueling. (A complete tabulation of receiver refueling requirements is presented in Appendix A.) This approach is preferred as being most generally applicable, particularly for the type of uses envisioned for CAFES. As is evident, functional flows progress through a logical refinement and breakdown reflected by several levels of indenture to establish an extensive baseline definition of system functional performance requirements. These requirements are to be developed to the lowest and most detailed level of indenture without regard to distinctive implementation modes, hardware concepts or man/equipment features and trade-offs.

The functional flow analyses may be carried to any necessary level of indent ure to appropriately reflect the systematic structuring of all functional requirements. When complete, they relate the following necessary element of information:

1) Mission phase
2) Phase function
3) Function activity
4) Man-machine interface action-information units to satisfy activity
5) Task characteristics that can be associated with each action-information unit

Functions and subfunctions are reviewed and analyzed in depth for probable variations related to the system requirements and operations. Even during early development, both alternative mission requirements and the expected downstream developmental impact of such alternatives are appraised to produce an early gross estimate of likely crew interface requirements, capability, special provisions needed, potential problems and probable solutions. In some cases, the human factors analyst may also need to produce preliminary workload data and to provide information for manning

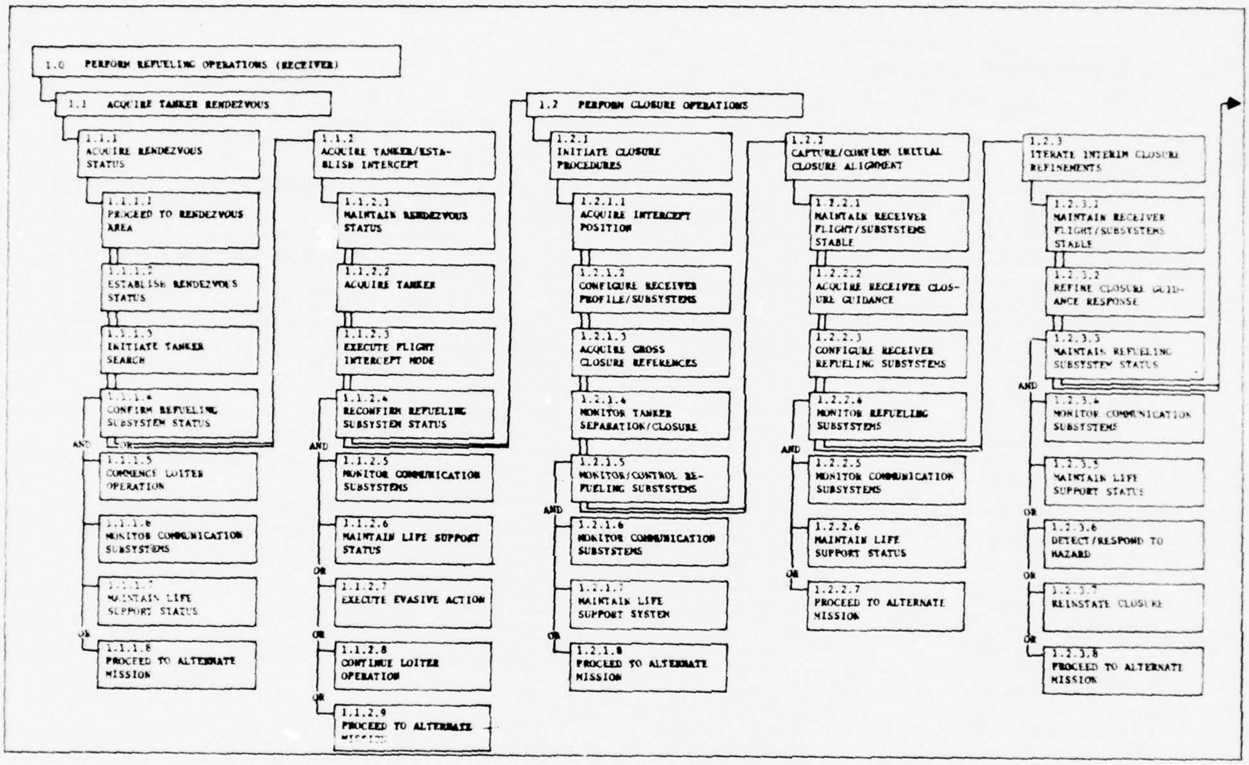


TABLE 2.1-7: FUNCTIONAL FLOW INDENTURES FOR REFUELING

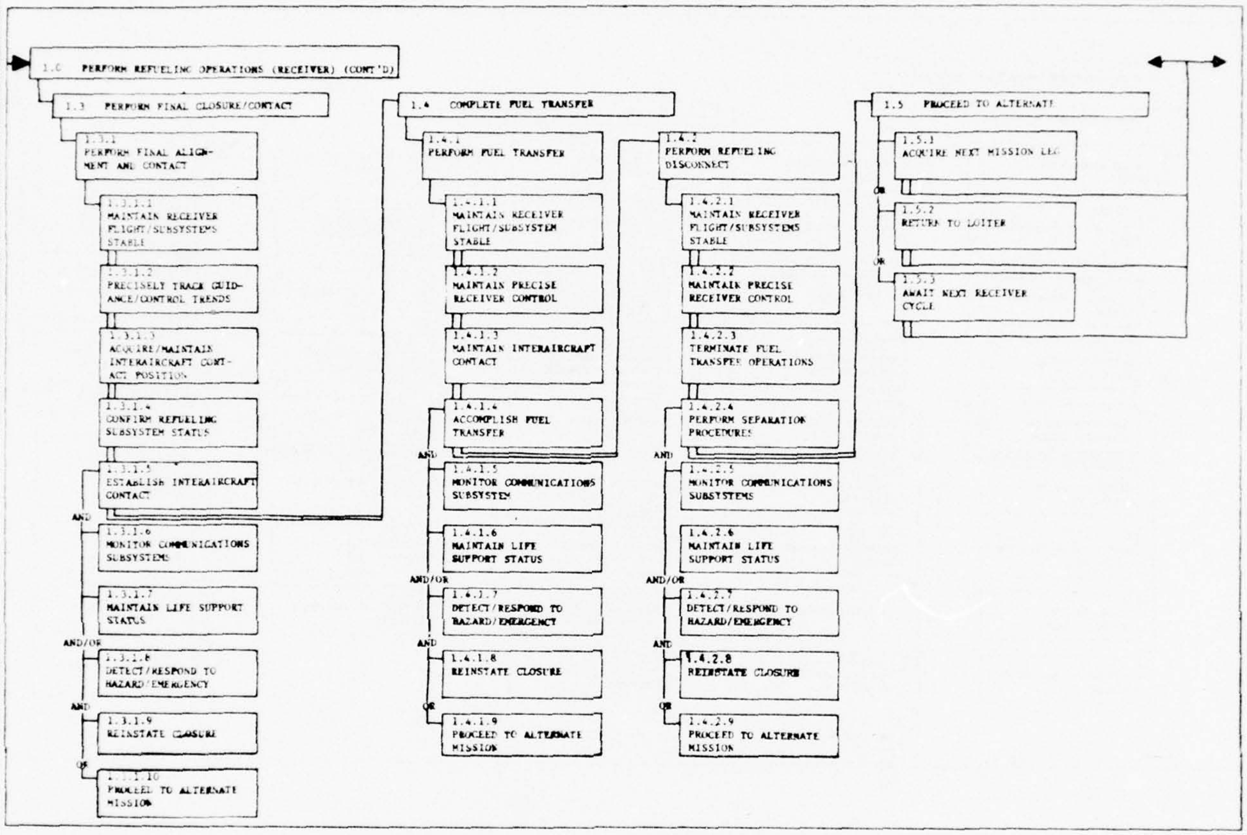


FIGURE 2.1-7 (CONTINUED): FUNCTIONAL FLOW INDENTURES FOR REFUELING

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS		
1.1.1 ACQUIRE RENDEZVOUS STATUS		
1.1.1.1 Proceed to Rendezvous Area		
1.1.1.1.1 Initiate/Control Flight Mode	- 1 Maintain Aircraft Configuration as Required	Normal Flight Modes
	- 2 Maintain Flight Profile as Required	
	- 2.1 Maintain Course to Rendezvous Area	Rendezvous Area Coordinates: Best Route, Planned Route
	- 2.2 Adjust Altitude as Required	Best Cruise Altitude; Planned Cruise Altitude
	- 2.3 Adjust Speed as Required	Best Cruise Speed; Planned Cruise Speed
1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	- 1 Operate Navigation-Guidance Subsystem	Navigation-Guidance Procedures; System Operation Status Positioning Accuracy; Position Latitude-Longitude; Course; ETA; Backup Modes
	- 2 Adjust/Maintain Propulsion Subsystem Operations	Propulsion Parameters; Normal Operating Range/Settings, Backup Modes
	- 3 Adjust/Maintain Power Subsystem Operations	Power Subsystem Parameters; Normal Operations Ranges/ Settings; Backup Modes
	- 3.1 Monitor/Control Electrical	
	- 3.2 Monitor/Control Hydraulic	
	- 3.3 Monitor/Control Pneumatic	
	- 4 Adjust/Maintain Fuel Subsystems Operations	Fuel Reserves; Tank(s) in Use; Fuel Rate
	- 5 Adjust/Maintain Auxiliary Subsystem Operations	Auxiliary Subsystem Parameters; Normal Operating Ranges/Settings; Backup Modes
	- 6 Monitor Caution-Warning Annunciaters	Systems Status-Normal/Abnormal; Annunciated Subsystems, Related Procedures; Backup Modes
1.1.1.1.3 Acquire/Confirm Rendezvous Area	- 1 Confirm Rendezvous Coordinates	Destination Coordinates, Characteristics
	- 2 Confirm Position Coordinates	Position Fix, Coordinates
1.1.1.2 Establish Rendezvous Status		
1.1.1.2.1 Establish Rendezvous Area Flight Parameters	- 1 Acquire/Maintain Rendezvous Configuration	Flight Control-Mode Changes for Rendezvous Loiter/ Intercept Flight
	- 2 Acquire/Maintain Rendezvous Profile	
	- 2.1 Acquire/Maintain Rendezvous Course	Preplanned Rendezvous Circuit: Track; Turns
	- 2.2 Acquire/Maintain Rendezvous Altitude	Preplanned Rendezvous Altitude, Altitude Profile
	- 2.3 Acquire/Maintain Rendezvous Speed	Reference Speed; Speed Changes
1.1.1.2.2 Confirm Aircraft Subsystems Status	- 1 Monitor/Control Navigation Guidance	Position Relative to Rendezvous Circuit; Estimated Time to Intercept; Subsystem Status
	- 2 Monitor/Control Propulsion	Propulsion Parameters; Rendezvous Reference Settings, Backup Modes

SHEET 1

FIGURE 2.1-7 (CONTINUED): FUNCTIONAL FLOW INDENTURES FOR REFUELING

2.2.1.3 (Continued)

and training estimates. At any rate, he must anticipate a wide variety of both normal and mission-specific possibilities to form a judgement for crew performance feasibility, support requirements and development needs.

In summary, functional flows provide a detailed and comprehensive inventory of all system requirements and an extensive checklist of system functions and considerations that must be considered in assuring ability to perform the mission. Properly structured, the inventory will proceed from functional indentures common to all similar systems (e.g., aircraft), through indentures peculiar to an aircraft type (e.g., fighters) and on to functional elements that are specific to mission operations. Detailed analysis of the functions is required to determine basic methods of achievement, possible equipments, and man-equipment trades in order to effectively determine which elements should be performed by equipment and which should be performed by man.

The key element of the functional flow analysis, for computerized storage and use, is the logical chain of carefully developed and clearly distinct functional requirements at each level of indenture. At the top level, a logical chain of unique functions is synthesized to meet a more gross functional need that could be titled "Complete Mission." Conversely, each top level function establishes a functional requirement that includes lower level, similarly unique and self contained sub-functions which define all necessary and related elements to satisfy its needs. This process carries on down through more and more detailed functions until all possible elements are identified, as available and identifiable performance objectives/criteria that can be associated with the functional elements.

Carried through the lowest level of indenture, the functional flows will incorporate extremely specific actions that must be performed to satisfy the functional requirement, and information that must be available to perform the related actions. The result is an extremely detailed and comprehensive inventory of every possible requirement for the mission. At this level of detail, there is less question as to what candidate

2.2.1.3 (Continued)

equipment will satisfy the need, if in fact such equipment exists (which is more readily apparent). Similarly, there are fewer judgemental factors in identifying and performing specific man-equipment capability trade-offs for a functions allocation.

Effectiveness of this particular activity is one of the most critical to establishing a standard baseline for any system (e.g., airplane) for use of CAFES. It is also one of the most difficult in terms of maintaining a consistent and logical chain in the structural breakdown. Most frequently, the tendency is to skip the logically structured chain of requirements and indentures and to get to specific hardware applications concepts as rapidly as possible. In this circumstance, the result may be unique to the system, the analyst or to the specific system concept at hand, and may lack the required generality for repeated use. Accordingly, a whole new development may become necessary for each new analyst or new system. (One such contrast was reflected in the distinctions in the functional flows for Figure 2.2-8 and the associated indentures of Table 2.1-6, in comparison with a similar intent for Figure 2.2-12 and Table 2.1-7, which is continued in Appendix A.)

2.2.1.4 Function-Action-Information Requirements

The analytic procedures for performing preliminary functions analyses are dependent on the analyst and his objectives. Several alternatives exist for this particular analyses, e.g., to make the allocation from the level of the detail provided by the functional flows. However, experience has shown that more task-related detail is desirable before making allocation trades. A format that has been useful in producing this detail in an appropriate context is system "action-information requirements" (Figure 2.2-13) or to carry this even further and reflect associated trade-off information and data (Figure 2.2-14). The action-information requirements define the specific actions necessary to perform a function and, in turn, those specific information elements that must be provided to perform the action. Another format is to define the action-information requirements as extensions and part of the functional flows (i.e., as more detailed levels of indenture).

System Function/ Requirements Common to all Approach Profiles		Action Requirements	Information Requirements
1.0	Initiate Pre-Approach Procedures	1.0.1 Review Approach Information	Approach Orientation Approach Constraints o Approach Requirements o Obstacles o Hazards o Weather Minima
		1.0.2 Coordinate Approach with Control	Communication o Path Designation o Unique Limitations/ Constraints o Environmental Conditions
1.1	Acquire Initial Nav/ Runway References	1.1.1 Determine Relative Runway Position and Orientation	Runway Position and Orientation Airplane Position and o Bearing/Range o Altitude Above Field o Heading/Track
		1.1.2 Assess Requirements for Runway Approach	Runway Position References A/C Position Reference Approach Profile Approach Path Constraints Environmental Limitations Guidance/Control System Performance Missed Approach Procedures

FIGURE 2.2-13: FUNCTIONAL ANALYSIS, REPRESENTATIVE DEVELOPMENT OF ACTION/INFORMATION REQUIREMENTS (ADAPTED FROM REFERENCE 44)

APPROACH REQUIREMENTS ANALYSIS			TRADE-OFF INFORMATION AND DATA INTEGRATION		
APPROACH-LAND FUNCTIONAL REQUIREMENTS	ACTION REQUIREMENTS	INFORMATION REQUIREMENTS	RELATED INFORMATION REQMT'S/ SOURCES/PROBLEMS	RELATED ACCIDENT FEATURES	RELATED SURVEY COMMENTARY
1.0 INITIATE PRE-APPROACH PROCEDURES	1.0.1 REVIEW APPROACH INFORMATION	1.0.1.1 APPROACH ORIENTATION 1.0.1.2 APPROACH CONSTRAINTS o APPROACH o REQM'TS o OBSTACLES o HAZARDS o WEATHER o MINIMA	APPROACH PLATE DATA o OBSTACLE LOCATIONS o COURSE/PATH DATA o TERRAIN CHARACTERISTICS o HAZARDS o MINIMUM DECISION ALTITUDES POSITION DATA	DATA MISINTERPRETED/ NOT USED EFFECTIVELY. HAZARDS MIS-APPRAISED. NAVIGATION POSITIONING ERRORS	o CAN'T REMEMBER ALL DETAILS o STUDY TIME IS LIMITED WHILE SETTING UP APPROACH o IMPROVE TO EMPHASIZE BASIC DATA- CRITICAL DATA BOLDER, eg, GO-AROUND HDG./ALT. o NEED CLEARER PICTURE OF POSITION SITUATION
	1.0.2 COORDINATE APPROACH WITH CONTROL	1.0.2.1 COMMUNCATION o PATH DESIGNATION o UNIQUE LIMITATIONS/CONSTRAINTS o ENVIRONMENTAL CONDITIONS o BAROMETRIC PRESSURE	COORDINATION AND CONFIRMATION OF APPROACH CLEARANCE ALTIMETER SETTING	CLEARANCES/PROCEDURES ARE MISUNDERSTOOD/NOT FOLLOWED/IN ERROR. ALTIMETER MISSET/ MISREAD. CONFUSION OF o INCHES MERCURY VS MILLIBARS o SEA LEVEL VS FIELD ELEVATION REFERENCE	o NEED PROCEDURES FOR BETTER COORDINATION BETWEEN AIRPLANE AND TRAFFIC CONTROL TO IMPROVE UNDERSTANDING OF SITUATION/ CONTROL INTENT o IMPROVE ALTIMETRY PRESENTATION METHOD o STANDARDIZE SETTING REFERENCES- FIELD ELEVATION PREFERRED FOR LANDING o REDUNDANT SETTING CHECKS o RADIO CHATTER/CHANGES

FIGURE 2.2-14: REPRESENTATIVE CORRELATION OF TRADE-OFF INFORMATION AND DATA WITH FUNCTIONS, ACTIONS, AND INFORMATION REQUIREMENTS

2.2.1.4 (Continued)

The resulting level of detail leads to the identification of specific functional elements for allocation. Additionally, the particular development that has been presented in the preceding outline and figures can be developed for a general purpose basic format, emphasizing fundamental operations that are not hardware specific (Figures 2.2-9 through 2.2-14). As is apparent, a number of relevant trades, decisions and candidate allocation concepts can be identified with early and preliminary definition of system requirements.

2.2.1.5 Candidate Control-Display Equipments Identification

Candidate equipment can be identified and listed tentatively for every detailed requirement indicated by the functional flow and action-information requirements. These candidates would cover all possibilities, including functions that are common to all such systems (e.g., aircraft) and to a type (fighters) as well as those functions that are mission specific. To the extent that functional requirements indicate a performance objective or criteria, the extent of equipment ability to satisfy the requirement can also be appraised. Equipment ability to satisfy several related or alternative requirements can also be identified. Finally, each piece of equipment has associated with it detailed task requirements. Accordingly, detailed task information is determinable for trade-offs related to completing functions allocations, for identifying task performance problems, for possible new concepts involving equipment-task integration, and for all subsequent phases of HFE efforts.

In summary, equipment characteristics related to detail functions can be identified and data obtained or made available to the extent that might be required for functions allocation trade-offs. Several trade characteristics, features and possibilities become more readily apparent at this level of detail, e.g., equipment reliabilities, capabilities; man-machine interface features; and related crew performance requirements (including such features as task elements, complexity, time accuracy and reliability); dimensions; weight; and cost.

2.2.1.6 Crew-Equipment Functions Allocation

At this point, particularly with functional flows and action-information requirements carried to quite detailed levels and candidate equipments and characteristics identified, the analyst will have the necessary information to perform a credible series of trade-offs to allocate functions to man and machine.

With the present HFE technological stare-of-art, there is no clearly definable way to outline all analyst decisions, operations and constraining man-equipment interface elements that might be involved in performing a functions allocation. The allocation process can be described, past experience and allocations can be used, and historical results can be applied. Programmable features for data retrieval and processing can be used to support this process and to validate results, or to compare alternative allocations. However, the ultimate decision and responsibility will remain with the analyst; he may accept the prior data or may choose an alternative because of some special mission feature or objective.

Following discussion summarizes information to be considered and describes an approach to performing the allocations. As a precautionary note, the actual quality of results in application will be dependent on the level of detail available, and will involve the technical knowledge and expertise of the analyst. However, the burden on the analyst will be reduced dramatically if preceding detailed information is available, and can be reduced much further if an analytic method of confirming allocations is applied for preliminary allocation concepts (e.g., The Functions Allocation Model and The Workload Analysis in CAFES).

In performing the actual allocation, the analyst can proceed systematically through all functional requirements and identify special or optional allocations covering candidate equipments to suit the need. Alternatively, he might identify new equipment or automation concepts that bear consideration or might be required, either to satisfy the mission or to integrate selected requirements. Specific assumptions that may be involved in performing functions allocations may also relate to general objectives or requirements such as variations in desired crew size and skills or the possibility

2.2.1.6 (Continued)

of intracrew task sharing. Judgements that may be required can vary dramatically; a range of parameters such as are indicated in Table 2.1-8 may bear consideration. Additionally, application of such trade-offs as are illustrated by the "Fitt's List" comparisons of man's capabilities versus equipment capabilities (Table 2.1-9) will be involved. Also, the man-machine interface characteristics that were outlined in Table 2.1-3 will be elements in such judgements.

Resulting allocations will remain to be verified in terms of such variations as probable success, crew number and skills, operational feasibility, and suitability. Limitations in past applications have been in the areas of: detail definition and consideration of all requirements, confirming that all possible requirements are met, providing specific consideration and comparisons of viable options, or establishing variations in levels of automation that might be desirable. Use of quantitative methods to perform specific allocation trade-offs has varied. Finally, verifying suitability of allocations analytically has tended to rely on detailed time line analyses and workload estimates (with iterative use of mockups and various levels of man-in-loop simulation).

Eventual completion of initial allocations are somewhat interactive with all subsequent activities. As performance of the analyses described later discussions indicates a problem area, resolution of the problem may well require re-examination of the initial allocations.

2.2.1.7 Gross Definition of Intracrew Tasks

Initial allocation of specific tasks to a given crewman is the responsibility of the human factors analyst. This initial task assignment may be done on traditional or experience grounds according to similar activities performed in like vehicles. This allocation provides the basis for assessing time line feasibility crew interactions for crew workload.

In early phases of system development, the human factors analyst is most interested in gross capability of given hardware systems to perform the

TABLE 2.1-8: PERSONNEL/SKILL ASSUMPTIONS

GENERAL

- Type
- Skills
- Skill Level
- Training Requirements
- Procedures
- Background
  - Experience
  - Education
- Response Characteristics
  - Quantity
  - Degree
  - Type
  - Level
  - Time
  - Accuracy
  - Interference
  - Ratings
  - Etc.
- Alternatives
- Practical Trade-Offs
- Other

MECHANICAL

- Physical Condition
- Size
- Strength
- Coordination
- Skill Level
- Alternatives
- Practical Trade-Offs
- Other

SENSOR MOTOR

- Vision-Acuity
  - Depth Perception
  - Contrast Perception
  - Color Perception
  - Response Time
  - Physiology
  - Pattern Recognition
  - Other
- Audition-Acuity
  - Tone Discrimination
  - Loudness Perception
  - Response Time
  - Physiology
  - Other
- Tactile-Acuity
  - Discrimination
  - Response Time
  - Other
- Other
- Alternatives
- Practical Trade-Offs
- Motor
  - Skills
  - Strength Force
  - Dexterity
  - Compatibility
  - Sensitivity
  - Other

PERSONALITY AND/OR CAPABILITY

- Aptitude
- Motivation
- Attitude
- Temperament
- Decisiveness
- Adaptability
- Analytic Capability
- Objectivity
- Idiosyncrasies
- General Personality
- IQ
- Practical Trade-Offs
- Other

MAN VS. MACHINE

MAN EXCELS IN	MACHINES EXCEL IN
Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Detecting signals in high noise levels	Exerting great force, smoothly and with precision
Ability to store large amounts of information for long periods - and recalling relevant facts at appropriate moments	Storing and recalling large amounts of information in short time-periods
Ability to exercise judgment where events cannot be completely defined	Performing complex and rapid computation with high accuracy
Improvising and adopting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (infra-red, radio waves, etc.)
Ability to react to unexpected low-probability events	Doing many different things at one time
Applying originality in solving problems: i.e., alternative solutions	Deductive processes
Ability to profit from experi-ience and alter course of action	Insensitivity to extraneous factors
Ability to perform fine manipulation, expecially where misalignment appears unexpectedly	Ability to repeat operations very rapidly, continuously, and precisely the same way over a long period
Ability to continue to perform when overloaded	Operating in environments which are hostile to man or beyond human tolerance
Ability to reason inductively	

TABLE 2.1-9: "FITT'S LIST" COMPARISON OF MAN'S CAPABILITIES VERSUS EQUIPMENT CAPABILITIES (From Reference 46)

2.2.1.7 (Continued)

function and gross man-equipment capability features affecting performance. The analyst, to perform his job most effectively, needs extensive data for review and preliminary decisions. He frequently must anticipate the detailed impact of the functions to be performed as the influence control/display requirements, selection, and performance features. Such information defines detailed crew tasks and workload.

Functional flows and functions analyses provide a comprehensive organization of all mission functions, from which gross function allocations and intracrew assignments may be made if desirable or necessary. Alternatively, the analyst may wish to perform the allocation and evaluate the timeline and/or workload implications, from which crew number requirements could be appraised (or alternatively, specific needs for increased automation could be deduced). Such activities refine the baseline for efforts relating to crew task definitions, control, display, and operations requirements, crew station configuration concepts, workload evaluations, crew station design, development evaluation, and the training, manning, and procedures requirements.

The human factors engineering analyst, at this point, has a detailed and well organized inventory and checklist of system functions to be performed, a correlated analysis of functional requirements, alternative allocation concepts and associated task requirements. The analyst must be able to convert these functions into specific man-equipment integration requirements and concepts, and to refine any additional data requirements for more specific definition of hardware items and tasks required of the crewman. The identification of the equipment, the tasks, the sequence of tasks, and the operations then become the basis for developing, comparing and evaluating candidate crew station concepts.

2.2.1.8 Operational Sequence Diagrams (OSD's)

OSD's are often applied around this point in developmental analyses (Figures 2.2-2; 2.2-3). The method, illustrated in Figure 2.2-15, is useful in tracking system information flow and decisions between crewmen,

2.2.1.8 (Continued)

between subsystems and between the men and equipment, e.g., the transfer at the man-equipment interface. It provides for assuring that there are no open loops in the chain of events involved in accomplishing a given function, and for verifying that the requirements are suitably met. It can be particularly useful in performing detailed evaluations of critical task events or for critiquing detailed characteristics of the man-equipment interface. For example, events and activities associated with a critical task can be traced back and forth between subsystems, between subsystems and operators, and between operators. With such detail, the analyst can verify that the solution is appropriate, that all necessary features of interface inputs and outputs are present, and that he comprehends the overall operation. Accordingly, he has the necessary information to isolate specific elements in the flow that are of import to the crew, and to evaluate suitability of the man-equipment interface (including the type of requirement, effectiveness of the man at performing the requirements, and appropriateness of interface design features for effective performance).

In actual practice, use of OSD's is a variable related to analyst preference. Through functions and task analysis or through formal OSD development, the intent is accomplished by the analyst. As illustrated in the representative diagram, the method is formal, detailed and laborious. Conversely, it is feasible to use the method at grosser levels, and some analysts use it in such a way. Regardless of analyst preferences, there is general agreement that OSD's are useful for those operations analyses involving critical tasks or interactions among several crew members.

2.2.1.9 Task - Workload Analysis

The primary purpose of a task analysis or a workload analysis is to confirm that task requirements can be met without undue difficulty and do not involve conflicting demands on the crewman; that provisions for task performance are effective; and that time and workload conditions are such that there is an adequate margin of task time to perform.

Task analysis includes task definition, covering crew actions, information requirements and crew performance capabilities vs. controls, displays

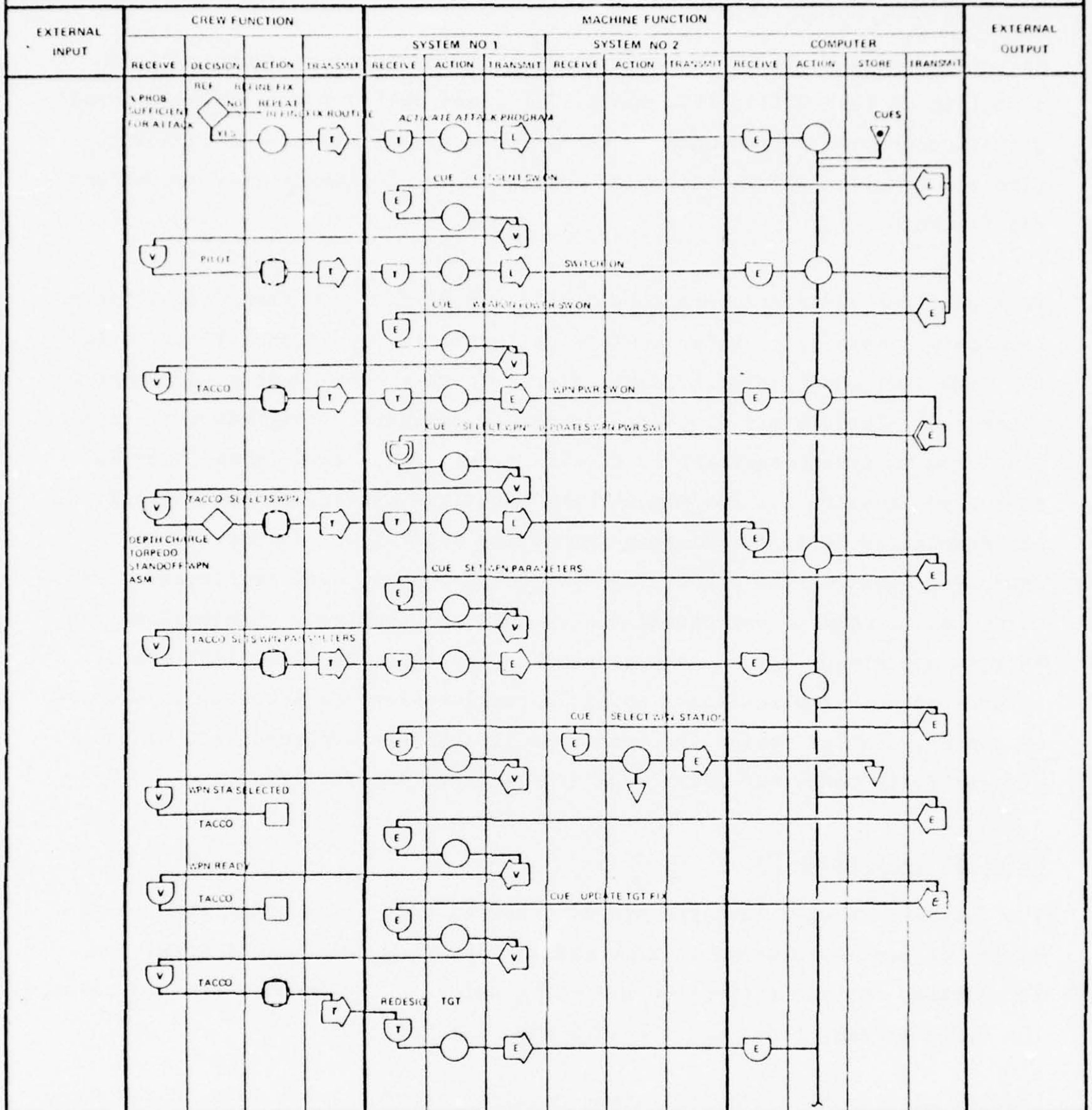
VPX OPERATIONAL SEQUENCE DIAGRAM

ATTACK SEQUENCE

PREPARED BY R. L. RICHARDSON

SHEET NO 1 OF 2

DATE 5 8 72



DESCRIPTION

ACTIVATION OF ATTACK SEQUENCE BY REQUESTING A WEAPON DROP (INTERCEPT) POINT CAUSES THE SYSTEM TO SOLVE THE FIRE CONTROL PROBLEM, SELECT WEAPONS AND TO PROVIDE STEERING CUES AS REQUIRED.

LEGEND

RECEIVE
ACTION
MONITOR
TRANSMIT
STORAGE
RECALL
DECISION
DOUBLE SYMBOL CONTINUOUS/ AUTOMATIC

A AURAL
E ELECTRICAL/ ELECTRONIC
T TOUCH
M MECHANICAL
S SPEECH
L LASER
IR INFARED
P PHOTO IMAGE
V VISUAL
RF RADIO FREQUENCY
EC EXTERNAL COMMUNICATION
IC INTERNAL COMMUNICATION

FIGURE 2.2-15: REPRESENTATIVE OPERATIONAL SEQUENCE DIAGRAM

associated crew performance requirements. Three elements accrue: (1) an appraisal of task difficulty, feasibility, and skills for refining control/display concepts and feedback to earlier processes; (2) task sequencing, time and timeline feasibility; (3) initial control-display-crew operations requirements.

Task analyses objectives are to complete and refine crew task definition and task data. Initially, this consists of converting functions allocated to the crew and control-display implications to task requirements and features. These task elements are evaluated to assure adequate provisions for effective crew-equipment performance of each task. Basic task feasibility is evaluated, constraints for man-machine interface operations are identified, and associated design/development needs are specified. Potential man-equipment combinations are evaluated for the type of crew performance features (e.g., skills, perceptual motor) that are involved. Limitations are further appraised for: system performance implications, practical significance of such implications; possible reallocation; or possible resolution by control-display design features. As limitations are resolved, control-display refinements and operations requirements are specified.

DETAILED TASK TIMELINE

The detailed mission timeline provides the base for evaluating both feasibility of task completion in time and of resulting crew member workloads. It provides for identification and correlation of the individual crew tasks, the order of execution, and the estimated time elapsed.

Initial mission timelines described earlier (section 2.2.1.2) amounted to gross task definitions, to begin the comparison of candidate equipment/man function allocations. The initial evaluation of the timeline is similar to the top level indenture of a functional flow block diagram, in that many tasks and individual elements are grouped into relatively long time frames in order to assess the impact for a crewman over the total mission segment. Successive iterations tend to concentrate on those segments of the mission which have critical time frame limits, critical work loads, critical activities requiring intense and all encompassing concentration

of the crew, or those activities with elements whose execution is mandatory for successful completion of the mission segment under investigation. (Figure 2.2-6 illustrates an initial timeline evaluation at the mission phase level; *Figure 2.2-16 illustrated a detailed second by second time-line* evaluation.)

The timeline is a chronological listing of the events expected to occur during the execution of a mission or mission segment. The human factors analyst is required to specify tasks to be accomplished and the duration of the activity, and time constrained limits.

Considerable data on task execution times are available in the literature, human engineering books and Industrial Engineering sources. However, these data may not be available in sufficient detail to assure direct applicability. In most instances it is necessary for the human factors analyst to improvise or synthesize performance time data to be able to complete the timeline. The data and methods described in the Data Store produced by the American Institute for Research may also be useful in this regard. Limitations in current data will, hopefully, be corrected as the fund of knowledge continues to build. Each systems development program should provide some additional information that can enhance a data storage system.

Based on representative, similar equipment and the type and number of operations or on expected equipment features, data used may be from empirical measurements for such equipment in a mockup or simulator, or from an analytic accumulation of the time required to perform distinct operations with the representative equipment (e.g., to adjust knob, flip switch, push button). If there is no similar equipment, it may become necessary to estimate from similar task elements on other equipment, or through mockup or simulation approximations of the activities in order to produce time estimates. Alternatively, if specific equipment, related task events and task sequences are available, analytic or mockup-simulation data should be readily obtainable.

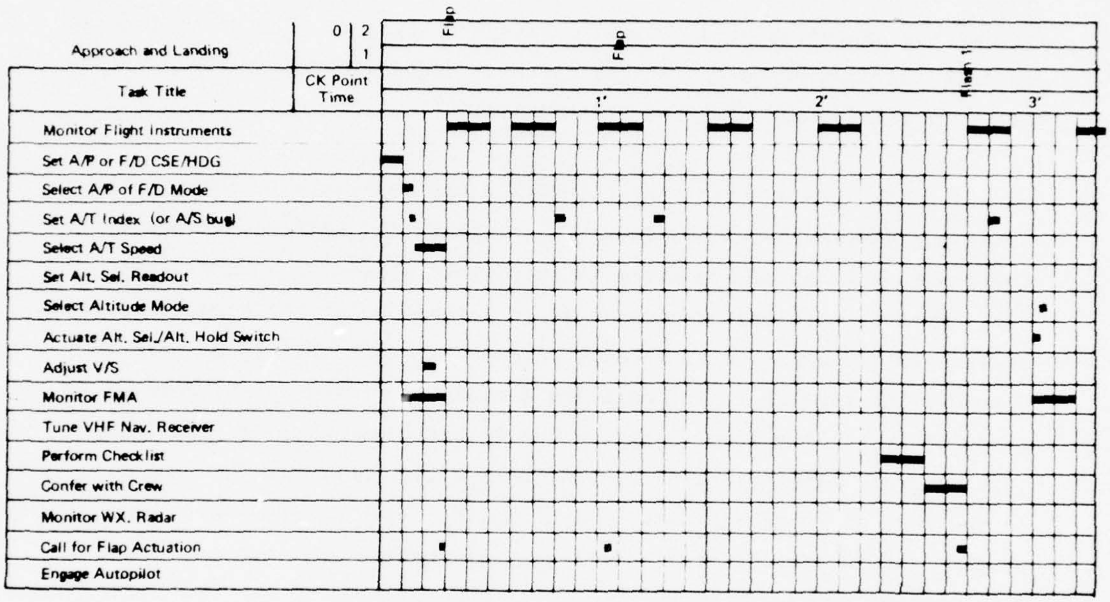


FIGURE 2.2-16: DETAILED TASK TIMELINE

TABLE 2.2-1: PRELIMINARY SUMMARY OF DATA SYSTEM REQUIREMENTS

2.2.1.9 (Continued)

At any rate, and particularly for tasks in critical mission portions, initial estimates or data will require refinement to the extent more specific equipment features and operational procedures are identified during system development. As detailed equipments and operations are defined in early analyses, related timelines will be reasonably stable. However, time to perform may be influenced by relative physical location of equipments in the crew station. Additional examination of critical events may be desirable when crew station configuration concepts are defined.

WORKLOAD ANALYSIS

Earliest possible workload appraisals are needed to assure that resulting task loads are within the scope of crew size and capability. Workload analysis is performed to determine if the accumulation of tasks per unit time can be performed by the crewman. The objective of such an analysis is to verify that no combination of tasks required of the operator take more task load capacity, skills, or time to perform than is available. Workload as a descriptor of effort has been a controversial term, primarily because of the number of variables that might be considered to be involved. Quantification of effort for applications as desired here has been difficult. Such related measurement as energy expended, heart rate, physical activity and many other elements are not readily responsive to short term workload peaks for measurement purposes, and are not readily usable as predictors for short time multi-task events. More definitive research may be desirable, but a more pragmatic application to present systems programs has been needed.

Industrial Engineering time and motion methods provided the framework for a concept which has been used in elementary manual applications. Using the task-timeline base, percent workload judgements have been made as to the extent of mental and physical effort or commitement involved at incremental units of time. Such features as detailed task characteristics and their "load" (tasks that overlapped each other in time) and known "workload" problem areas (from past experience) could be used to appraise the

2.2.1.9 (Continued)

relative workload for a new concept. In application, the analyst could make informed judgements about both the amount of crew "involvement" and the amount of reserve capacity that might remain, and then chart estimated workload levels. Reasonable agreement between analysts is generally observed in the results from this methodology.

Basic principles and procedures have been developed which permit workload comparisons between system concepts. One such method recognizes that an operator simultaneously performs several functions in accomplishing a single task, i.e., visual auditory, cognitive, and physical motion (e.g., right hand, left hand, amount of travel). The point is, effective evaluation of workload requires recognition of the fact that several operator "channels" are involved in a task, and conversely other "channels" are relatively free for performance of other tasks.

Improved methodology was desirable. However, computer capabilities were necessary to most fully develop this methodology. The CAFES Workload Analysis Model is the present evolutionary stage of this method.

2.2.1.10 Crew Station Configuration Concepts, Trade-Offs and Design

Initial objectives for this evolutionary process are to identify and evaluate feasible crew station configurations to select a specific concept. Such objectives phase into the physical design, development and evaluation of a given configuration. Typically, this process has been starting simultaneously with, or even preceeding the HFE analyses. More ideally, it should follow the analyses.

In early stages, the crew station designer should have at least such information as (a) the mission requirements, candidate control-display equipments, internal and external vision requirements, correlated task requirements, crew visual-physical access needs, seating and ingress/egress needs and possible crew complements; (b) specifications, standards and design handbook requirements, covering the full range of crew station design variables; (c) approximate dimensions and arrangement of the unoccupied space;

2.2.1.10 (Continued)

(d) general ground rules to work by, such as criticality of a task or operation, frequency of use and functional grouping of controls and displays, and (e) anthropometry of the operators, and (f) more or less standardized design practices, based on experience, comparable systems and analogeous situations. For example, the requirements in Military Standard MIL-H-1472 are relevant throughout this process. From such inputs, and from his ingenuity and ability to conceive new concepts or alternatives that satisfy the needs, he effects the necessary compromises and integrations to develop candidate configurations. These are typically refined during development of preliminary drawings, and "soft" mockups are used for further comparison, refinement and evaluation. Multiple critiques from multiple viewpoints are applied. Use of the mockups may vary from performing individual compliance checks for display, control or arrangement, through evaluation of provisions for a given series of tasks, to an evaluation of overall effectiveness by mentally and verbally progressing through the mission scenario. Improved or new concepts may also be mocked up. Selected areas may be further examined by transferring evaluations to a part-task simulation.

The eventual result from the various critiques and evaluations is the selection of a specific configuration with necessary refinements. With this selection, physical design, development and evaluation undergoes continuing iteration of any of all prior processes, as required to assure an effective crew interface is evolving that meets requirements of the developing system and provides for necessary crew performance. This latter activity phases from design mockup evaluations through increasingly representative simulation and hardware development, and proceeds on through flight evaluations. During the process, the configuration becomes firm and less responsive to system design changes for any problems and solutions other than those that can be solved by procedure changes or those that involve major safety-of-flight items.

All these activities are sufficiently familiar and relatively standard in the design process, so that there is no need for extensive discussion of the typical problems and the types of solutions that have been applied.

2.2.1.10 (Continued)

The key point to be made is that the efforts outlined previously will significantly improve on the typical limitations that are exposed at this development stage.

Results lead into the test and evaluation program, with the objectives to demonstrate that the overall development suitably meets mission requirements and that the system can be controlled, operated, maintained and supported by trained personnel.

2.2.1.11 Manning, Training and Procedures Requirements

Cost of system operation and maintenance in terms of personnel is directly and demonstrably reflected in these elements. Effectiveness of main HFE provisions will show up in this area, as number and types of personnel, required skill levels, and extent of training required.

As typical system programs phase into operations, large complements of personnel with appropriate entry skills must be preselected and trained, provided with necessary operations and maintenance handbooks, and prepared to test, evaluate or otherwise apply the system. Personnel who are knowledgeable, prepared and equipped must be ready to accept each hardware element as it comes off the line and perform any and all related functions. Accordingly, and in parallel with design and fabrication efforts: personnel numbers and skills are established; training requirements, planning, courses and instruction are defined and accomplished; and technical publications providing operation and maintenance instructions and data are being produced.

Information on systems and related tasks provides the starting point for detailing the training program requirements, selection of training methods, and both identifying and initiating development of required training equipment.

In order to meet the overall requirements and have qualified personnel available as the equipment becomes available, manning, training and procedures specialists must forecast many of the hardware developments and

initiate related activities. Earliest possible definition of manning, training and procedural requirements is required in order to structure the programs. Both past experience with similar systems, detailed functional flows and other analytic results are reviewed and evaluated for implied operation and maintenance needs. Accordingly, the quality of early definition is dependent on the level of experience and on the amount of detail provided by the analytic data. Additional definition is accomplished as design decisions are made and as task analyses are completed.

Manning, training, and procedures requirements interrelate with and are dependent on the type of data provided by the human engineering development of task and equipment data, task-timeline analyses and workload analyses, and are directly affected by corresponding decisions. Needed data includes all elements of both traditional and new systems tasks. Manpower levels and skills are similarly dependent upon tasks and task structure. Training, and procedures requirements are similarly dependent in terms of (1) deriving specific training objectives and (2) defining requirements for existing and new skills, curricula needs, and training, operations, and maintenance manuals.

The point is that detailed development of these requirements is dependent on HFE products which convey, among other information elements, the type and difficulty of training tasks. If such information is not available, the training analyst must rely heavily on past experience and progressive design decisions. Most typically, the HFE analyst and the training/manning/procedures specialist are working in parallel, so that extensive coordination is required to maintain currency on unpublished information. As the analytic process moves on, the HFE is producing very specific task-definitive information. Recording and transferring this information provides the detailed data that can be used to develop training requirements and objectives, and that help to refine manning and procedures needs.

The refinement of candidate equipment subsystems and components during successive iteration of crewstation evaluation helps to further refine the

2.2.1.11 (Continued)

type of training functions and skill mixes. For example, the specific activities of support crews will be partially defined once equipment candidates become known. The equipment candidates will have associated replacement maintenance requirements which may be used to further establish training, manning, and procedure requirements for support and maintenance.

The objectives, depth and detail of training is subject to judgement by the training analyst, just as much of the selection of equipment candidates for an unknown developmental system is subject to the judgement of the human factors analyst. He can make extensive use of developmental information described previously in this report.

2.2.2 HFE Methods and Data Requirements - Desirable Developments and Improvements

The methodology outlined in preceding portions of this report is only one of many possible approaches. It does not adhere to the full range and sequence of techniques that are available and that have been used. However, it has been applied and demonstrated to work as intended. It does provide a vehicle for systematically narrowing the overwhelming range of potential HFE considerations to specifically structured requirements related to specific mission roles. This approach helps to scope and constrain the type and quality of data that might be needed for those key data elements which are necessary and sufficient to make appropriate HFE decisions.

Several HFE data requirement concepts emerge from the approach that has been described. The following discussion highlights six major data areas that have been identified from preceding sections. Discussion then turns to a more extensive description of task data considerations and equipment data considerations.

2.2.2.1 Desirable Developments

First, it would be advantageous to have available for ready access and use generalized mission scenarios and a full set of representative basic functional flows reflecting common functional requirements for each of several major weapon systems (e.g., aircraft, ships, command and control systems). Further breakdown for types (e.g., fighters) would also be useful, This would alleviate a major work effort that applies from new program concept definition and early evaluation of related problem areas, and carries throughout design, development, test and evaluation. Access to such a baseline would make feasible a very thorough review and check-off of concept implications for HFE, even from early summaries of preliminary operating requirements. Detailed development of such information is desirable. CAFES has the capability to accept and process such data, once developed.

Secondly, it would be desirable to initiate a tabulation of commentary, problems and alternative solutions related to each functional requirement.

2.2.2.1 (Continued)

This would provide invaluable information for the HFE analyst in making trade-offs and decisions in preliminary functions allocations. Initiation and continuation of such information is desirable. A format such as was illustrated in Figure 2.2-14 could be used for this purpose.

Thirdly, the appropriate definition, management, organization and integration of task data is a continuing quandary; a data system with data bank is needed, and improvements in technological data comparability and utility will also be a continuing requirement. In lieu of setting predictive criteria, present methods are to assimilate elements of empirical data to establish an accumulated prediction of ability to meet an external criteria. This condition will likely continue for some time. Much of the available HFE data is not directly comparable, is frequently incompatible and is often contradictory. Even with a common data element that could be applied throughout a system mission analysis (such as human reliability) the comparability of concepts is difficult to establish for such events as probability of target acquisition versus probability of correctly selecting a routine communication channel. Even if comparable, performance constraints that dictate task criteria are quite variable - dictated by mission operations, mission phases and the criticality of operation. (For example, task tolerances and associated criteria are extremely broad during routine cruise flight, and conversely are extremely narrow during landing.) Relevance of criteria are as variable, with such distinctive requirements as physical size and strength, skill levels, vision characteristics and many others. An information system concept for HFE data is needed; given this concept, CAFES data management capability could be used.

Fourth, equipment variables effecting task performance capabilities impact the HFE process in providing for effective crew performance in many ways. Few equipments are identical, so that each similar piece may satisfy common, similar and unique functional requirements. Physical characteristics also differ, with three variations of consequence: (a) the physical volume, weight and cost parameters; (b) the physical man-equipment interface parameters; and (c) interface operations-workload parameters such

2.2.2.1 (Continued)

as - the types of performance involved; task performance steps, repetitious, qualifications and time; and task criticality to the system mission. Early initiation of a data concept and data tabulation is recommended.

Fifth, numerous design constraints are imposed in merging requirements for operations, crew performance, physical crew station volume, physical relationships of crew access and anthropometric needs versus the crew station layout, and equipment characteristics. Some such constraints are contradictory, such as the requirement for 28-inch forward panel viewing distance versus 30-inch clearance for ejection seats. Additional integration methods are desirable that would enhance the access to and synthesis of data and constraints from various sources, and would also enhance the transition of such information into the most generally suitable design concepts.

Sixth, elements of the activities in developing requirements for manning, training, and publications could benefit more directly and extensively from HFE data. This could be accomplished if progressive definition of HFE analyses and data either provided direct visibility of data relevant to their needs, or permitted ready extrapolation as required. Many interactive technology needs are indicated in present developments of Specific Behavioral Objectives and Instructional System Design, e.g., in detailed task data, in relative skills and in number of crewmen. More definitive efforts to enhance the data transfer and utility for this intertechnology interface is desirable.

2.2.2.2 Task-Equipment Data Requirements and Criterion Considerations

General ultimate criteria for task performance by crewmen is in the form of successful, sustained use of equipment for effective system performance. However, criterion parameters for effective performance will fluctuate with the mission phase, precluding a simplistic overall criteria. For example, criterion elements for aircraft systems performance during landing are dramatically different from the criteria applied during weapon delivery. In either case, the criteria are established by the mission

2.2.2.2 (Continued)

phase and are unique in setting the performance objectives for selected man-equipment combinations applicable to the phase. In other words, the true criteria for task performance are established by the operational context and criticality for performance. Performance quality and emphasis will fluctuate with selected critical operations that are phase related. Accordingly, with today's HFE state-of-art, both qualitative and quantitative data considerations are involved. The related data problem thus becomes one of developing a concept for effective HFE use of both data types.

In general, the information required to perform human factors engineering analysis includes:

- o Human performance data,
- o Equipment characteristics and performance data,
- o Specifications and standards to be applied.

In addition to availability of such data, improved provisions are required for the storage and retrieval of pertinent data in order to minimize the reaction time for human factors analysts to provide trade-off results or design information to subsystem designers. While the crewman is a vital part of the subsystem, related design data must precede the finalizing of the configuration and structure of the vehicle.

Ultimately, the task information on human performance should include:

- o Nominal task performance data,
- o Effects of operating conditions on performance,
- o Differential performance characteristics,
- o Applicable standards and specifications.

Nominal task performance data are needed to define the overall capability of a crewman to perform a specified task. Once the question of task

2.2.2.2 (Continued)

performance capability has been settled, it is then necessary to determine whether the performance is within time constraints, and within acceptable reliability standards. The following discussion expands on data needs.

The nominal task data involves consideration of at least the following:

- o Performance time,
- o Accuracy,
- o Reliability
- o Additional behavior characteristics
  - Cognition and decision response
  - Reaction time
  - Force generation
- o Error type, magnitude, and frequency.

The effects of operating conditions on performance are also required. This definition is to detail the capability of the crewman to complete the required task in a satisfactory manner. The change in operating conditions effect changes in priorities which may modify parameters, such as:

- o Performance mean values
- o Performance variability
- o Group performance
- o Probabilities of successful completion.

The capabilities of individuals may be modified to some extent by training, to assure performance of specific tasks in a more satisfactory manner. The amount of change required to alter performance is a function of previous experience and knowledge. Accordingly, the additional characteristics that might be needed for each type of task could also include:

- o Entry level education and skills
- o Special training requirements
- o Predictive performance measures.

2.2.2.2 (Continued)

Additionally, relevant data from the specifications and standards applicable to all human factors designs are required. The central listing of these items will provide the analyst with ready access to the information. The listing also provides a checklist which decreases the chances of overlooking pertinent requirements.

2.2.2.3 Data System Requirements

A data system for storage and retrieval of human factors engineering information is needed for use in the performance of both manual and computerized HFE methods. The different stages of analysis may require different or varying level of detail. In addition, not all areas of required data will have the same depth of information available.

Both the conceptual framework and the format of data storage for ready access, comparisons, use and/or updating is an important aspect of data system utility. With the format adopted, the user must be able to readily obtain the level of sufficient detail necessary to satisfy his needs. Capabilities and limitations summarizing the entire package of information on a given human task, or equipment item, needs to be presented in order to prevent masking of subtle constraints or complicating interaction effects. Where multivariate relationships exist, it is essential that these items are identified and present in the stored data. Additional data qualifications that can be relevant include such variables as:

- Validity
- Recency
- Credibility (e.g., estimates, calculated, measured)
- Accuracy
- Any special qualifiers

Finally, it may become necessary for the HFE analyst to retrieve and evaluate data from the original data reference. Accordingly, data should be recorded as to the date, author and source, i.e.,

2.2.2.3 (Continued)

- o Experimental literature
- o Field data
- o Contractor derived system design data
- o Handbooks, guides, and manuals
- o Subjective data from expert opinion.

In summary, the real requirement for present purposes is for a data system that provides for the systematic coding, storage and retrieval of information. A simple data bank concept is unlikely to be adequate. The system employed for storing data must be organized to permit ready access to any individual data element as required for review and use as entered, or for data entry and updating. Table 2.2-1 presents a preliminary tabulation of the types, formats and trade-off factors to be involved in development of the data system.

2.2.2.4 Data System Applications Concept

Conceptually, the pragmatic problem for the HFE analyst is in identifying and appropriately integrating both the qualitative information and the quantitative data which is minimal and sufficient to predict or appraise effectiveness of task performance relative to system requirements. Numerous approaches could be applied to resolving this problem. However, only one will be expanded here in terms of present purposes to develop a "single thread" process for HFE analyses and CAFES for applications.

Two major constructs can be interrelated into one approach: to track and correlate mission requirements, constraints, tradeoffs influencing task performance on the one hand, and to tabulate and use equipment related tasks and performance data on the other hand. The first construct is functional requirements oriented and assumes that basic and detailed functional flows are developed or will become available for each system (e.g., aircraft) that might be of concern. The second construct is equipment oriented and involves the storage and use of task performance requirements and data as related to given crew station equipment.

TABLE 2.2-1: PRELIMINARY SUMMARY OF DATA SYSTEM REQUIREMENTS

Data requirements

A. Data Types
   1. Effect of operational conditions on task performance
      a. Task requirement/tolerance changes - accuracy, timeliness, probability
      b. Changes in behavior - effects of stress parameters
         1) Performance variability
         2) Performance mean values
         3) Group performance
         4) Probability of successful completion.
   2. Differential performance characteristics - key task related
      a. Skills, skill level
      b. Educational level
      c. Special training
      d. Other correlates predictive of performance
   3. MIL-STD or other task/performance/equipment guideline
      a. Data coded for compliance with standard
      b. Standard's data retrievable
   4. Nominal task performance data -- task elements
      a. Speed
      b. Accuracy
      c. Reliability
      d. Additional behavioral capabilities (cognition/decision responses, reaction time, force gen., etc.)
      e. Error type, magnitude, frequency
   5. Equipment data
      a. Performance characteristics
      b. Operating requirements and description

B. Data Format
   1. Capacity to call up the level of detail required
   2. Total task information presented (prevents masking interaction effects)
   3. Capability for multivariate relationships to be presented or displayed
   4. User organizational freedom--access requirements and output flexibility
   5. Multi-access schema
   6. Operational terms employed to facilitate data retrieval
   7. Updating must be simple to enhance appropriate task-equipment access and data expansion
   8. Rapid hard copy (user option)
   9. Summary of data at a prescribed level be available

C. Data Sources and Qualifications (Retrieval Source, Date, Author to Be -- Displayed with Data)
   1. Experimental literature
   2. Field data
   3. System design phase - contractor derived
   4. Handbooks, guides, manuals
   5. Expert opinion - subjective data

D. Data Store Development
   1. Establish overall framework to permit systematic growth
   2. Optimize and encourage data availability

2.2.2.4 (Continued)

In the first construct, the ultimate level of detail developed by the functional flows or other analysis techniques would be extended to reflect experience, unsatisfactory reports and trade-off data much as previously illustrated by Figure 2.2-14, and repeated here as Figure 2.2-17 for reader convenience. Characteristics of relevant variables concerning the man-equipment interface and operator performance features were tabulated in Table 2.1-3. That information is also repeated in Table 2.2-2 for convenience. At a minimum, this approach would facilitate maximum use of available information and data by the analyst for readier appraisal of response characteristics that could influence performance, e.g., response type, difficulty, consistency, peculiarities, variability, range and impact on mission performance. It could also facilitate more systematic identification of data gaps and appraisal of both the significance and consequences of such gaps.

An additional feature of the construct is that the level of indenture would carry to that level of detail where specific requirements involving man-machine interface units are identifiable, along with candidate equipments, task requirements and constraints or trade-off features. Known candidate control-display equipments would also be identified at this level. However, the construct would retain the flexibility to modify preprogrammed information in order to better fit specific mission requirements, or to incorporate new equipment concepts, inventions or trade-off information as relevant and desirable. Accordingly, the construct encompasses the necessary features and adaptability to reflect all possible mission requirements, to incorporate innovative solutions, and to retain assurance that all requirements are suitably met.

The result is a concept that relates directly to earlier discussions covering the analytic process from early functional flows and will not be further expanded in this section. It does not offer a straight forward clearly quantifiable progression for HFE application. However, it does provide for the systematic recording of information against the functional flow indentures. It also provides for increased assurance that HFE

APPROACH REQUIREMENTS ANALYSIS			TRADE-OFF INFORMATION AND DATA INTEGRATION		
APPROACH-LAND FUNCTIONAL REQUIREMENTS	ACTION REQUIREMENTS	INFORMATION REQUIREMENTS	RELATED INFORMATION REQMT'S/ SOURCES/PROBLEMS	RELATED ACCIDENT FEATURES	RELATED SURVEY COMMENTARY
1.0 INITIATE PRE-APPROACH PROCEDURES	1.0.1 REVIEW APPROACH INFORMATION	1.0.1.1 APPROACH ORIENTATION 1.0.1.2 APPROACH CONSTRAINTS o APPROACH o REQM'TS o OBSTACLES o HAZARDS o WEATHER o MINIMA	APPROACH PLATE DATA o OBSTACLE LOCATIONS o COURSE/PATH DATA o TERRAIN CHARAC-TERISTICS o HAZARDS o MINIMUM DECISION ALTITUDES POSITION DATA	DATA MISINTERPRETED/ NOT USED EFFECTIVELY. HAZARDS MIS-APPRA-ISED. NAVIGATION POSIT-IONING ERRORS	o CAN'T REMEMBER ALL DET-AILS o STUDY TIME IS LIMITED WHILE SETTING UP APPROACH o IMPROVE TO EMPHASIZE BASIC DATA- CRITICAL DATA BOLDER, eg, GO-AROUND HDG./ALT. o NEED CLEARER PICTURE OF POSITION SITUATION
	1.0.2 COORDI-NATE APPROACH WITH CONTROL	1.0.2.1 COMMUN-CATION o PATH DESIGNA-TION o UNIQUE LIMITA-TIONS/CONS-TRAINTS o ENVIRONMENTAL CONDITIONS o BAROMETRIC PRESSURE	COORDINATION AND CONFIRMATION OF APPROACH CLEAR-ANCE ALTIMETER SETTING	CLEARANCES/PROCED-URES ARE MISUNDER-STOOD/NOT FOLLOW-ED/IN ERROR. ALTIMETER MISSET/ MISREAD. CONFUSION OF o INCHES MERCURY VS MILLIBARS o SEA LEVEL VS FIELD ELEVATION REFERENCE	o NEED PROCEDURES FOR BET-TER COORDINATION BETWEEN AIRPLANE AND TRAFFIC CON-TROL TO IMPROVE UNDER-STANDING OF SITUATION/ CONTROL INTENT o IMPROVE ALTIMETRY PRESEN-TATION METHOD o STANDARDIZE SETTING REF-ERENCES- FIELD ELEVATION PREFERRED FOR LANDING o REDUNDANT SETTING CHECKS o RADIO CHATTER/CHANGES

FIGURE 2.2-17: REPRESENTATIVE CORRELATION OF TRADE-OFF INFORMATION AND DATA WITH FUNCTIONS, ACTIONS, AND INFORMATION REQUIREMENTS (FIGURE 2.2-14 REPEATED)

TABLE 2.2-2: REPRESENTATIVE OPERATOR PERFORMANCE VARIABLES

Human Factors Interface (Information-Control Factors)	PERFORMANCE FACTORS/CONSIDERATIONS/TRADE-OFFS (CAPABILITIES/LIMITATIONS/CONSTRAINTS)			
Data Sensing Modes (Display Modes-Vision; Audition; Tactile; Muscleposition/Kinesthesis; Smell)	Access/Display Location Functional Requirements/ Grouping Sensor-Function/Capability Type/Intensity of Signal Discrete/Continuous/ Intermittent Signal Accuracy Reaction Type/Time	Logic Diagrams Pattern/Trend Information Display Correlation Display Symbology Methods Display Clutter Feed Back on Status/Change Static/Dynamic Cueing Direction of Movement Cues Coding/Size/Shape/Color	Reliability Criticality/ Error Impact Resolution/ Sensitivity Fatigue/Alert-ness Trainability Other	
Decision/Judgment Factors (Data Interpretation-Processing/ Integration/Diagnosis/Prediction)	Type/Number of Steps Extent of Integration Extent/Type of Diagnosis Problem Complexity Procedures Complexity Display-Control Correlation	Communication Requirements Conflicting Factors Ambiguity in Data "Set"/Expectancy Display Emphasis Stress/Criticality	Knowledge/ Familiarity Memory Retention Habits Trainability Other	
Control Operation Factors (Manual/Motor Capability and Skills)	Access/Control Location Functional Requirements/ Grouping Reaction Type/Time/Rate Force/Distance/Direction Discrete/Continuous/ Intermittent Actions	Correlated Displays Correlated Actions Operations Sequence/ Frequency/Criticality Logic Diagrams Coding(Designation/Size/ Shade) Procedures	Reliability Error Impact Skill Completion Dexterity/Retention Trainability Other	
Work Space Envelope (Station Layout/Human Anthropometry/Mobility Required)	Display-Control -Arrangement/Functional Grouping (Position Correlation) -Access/Reach	Motion Links/Constraints/ Time Procedural Interrelations Workspace Size/Layout	Other	
Environmental (General Impact on Performance/ Physiology)	Lighting Temperature Humidity	Airflow Fatigue/Alertness Noise	Emergencies Operating Stress/ Constraints	
General (Overall Effects/Constraints)	Priorities Stress Time Constraints	Operations Criteria -Qualitative -Quantitative	Workload Safety Standards	State-of-Art Tradition/Acceptance

2.2.2.4 (Continued)

decisions take into account both basic mission parameters and all relevant task performance variables. In the near term application it will provide an interim technological base for improving the scope of relevant areas covered by HFE efforts while the state-of-art for a quantitative data base is being further refined and developed. It also offers a framework for continuing incorporation and use of either quantitative information that may not be comparable, or qualitative information that may never be quantifiable.

The second construct relates directly to the candidate man-machine interface equipments that are identifiable at the ultimate level of indenture in the functional flows or other analytic results. It accepts the notion that new systems may make extensive use of pre-existing (traditional) controls and displays for which tasks are defined and task data can be obtained. Alternatively, the system may use new control and display concepts which have been developed and confirmed sufficiently for data to be available. The point is that few, if any, new systems will involve radical and revolutionary changes in the total state-of-art that are so dramatic as to invalidate all prior functional requirements, associated equipment and data. Accordingly, task performance requirements and data can be tabulated and recorded for each item that is identified from the functional flows. In turn, pre-existing data on equipment-related tasks can be retrieved and used as each becomes a candidate in the functions-allocation process. Similarly, data on hardware characteristics and performance can be stored for retrieval and use as required (e.g., weight, volume, interface signals, display-control features).

Accordingly, the second construct is oriented toward man-machine interface equipment, i.e., controls and displays. This construct has evolved over several applications developments, with the most recent and extensive investigations sponsored by the Boeing Commercial Airplane Company. Titled Cockpit Information Storage and Management System (CISMS, Reference 42), the present development is concerned specifically with the aircrew cockpit and associated hardware. It provides for definitive hardware

2.2.2.4 (Continued)

specification and for data storage and retrieval covering variations in operation according to flight phases, flight requirements, flight functions subsystem elements, and control-display functions. With the hardware items specifically identified, additional information is included that covers: functional capabilities of the hardware; interaction requirements between the operator and equipment; task related information (e.g., time, constraints, performance reliability); and such physical characteristics as volume, weight and power input requirements. In general, data updating can be accomplished directly for the equipment for which new data applies. An example of the overall construct is illustrated in Figure 2.2-18 and the detailed equipment areas are shown in Figure 2.2-19.

Application of the overall data system concept would be to retrieve and adapt the functional requirements flows of the first construct, through the crew station equipment candidates. Candidates could be identified by the HFE analyst at this point, or he could retrieve and review the equipment data of the second construct before making such selections. In either case he has ready access to all relevant data for making initial functions allocations and progressing through the HFE activities described in the first section of this report.

Such concepts and data as are described above apply for both manual HFE methods and those methods augmented by computer aids. In both instances, the intent and type of effort are essentially the same, but the extent of effort required and level of depth supporting the results will differ markedly. The difference is that the manual process will tend to be far less comprehensive without a rather extensive baseline being made available. Similarly, detailed or iterative calculations will be less likely. On the other hand, development of such a baseline does allow for most effective use of qualitative information and of professional skill, experience and judgment. Additionally, in any new application, the computer can supplement the process by first retrieving, organizing and presenting information for the HFE analyst to review, critique and modify; secondly, reorganizing the information as instructed; and finally performing such calculations and iterative operations as are required.

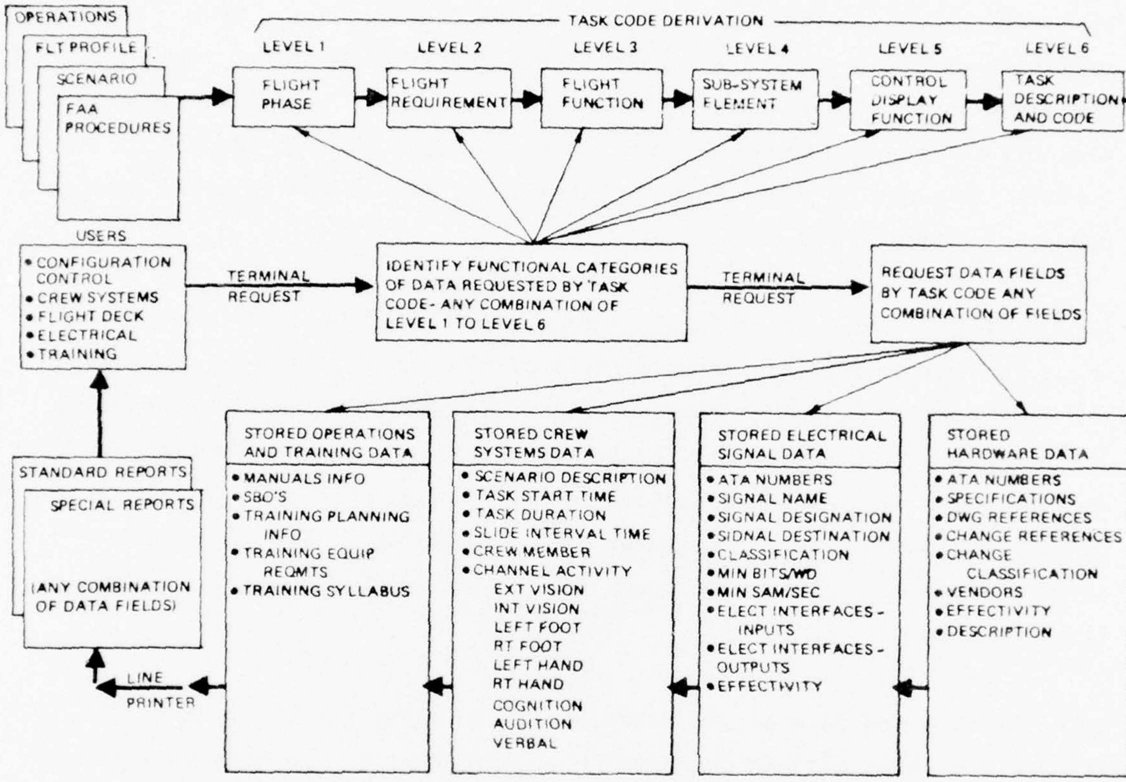


FIGURE 2.2-18: CREW SYSTEM INFORMATION STORAGE MANAGEMENT SYSTEM (CISMS) DATA FLOW

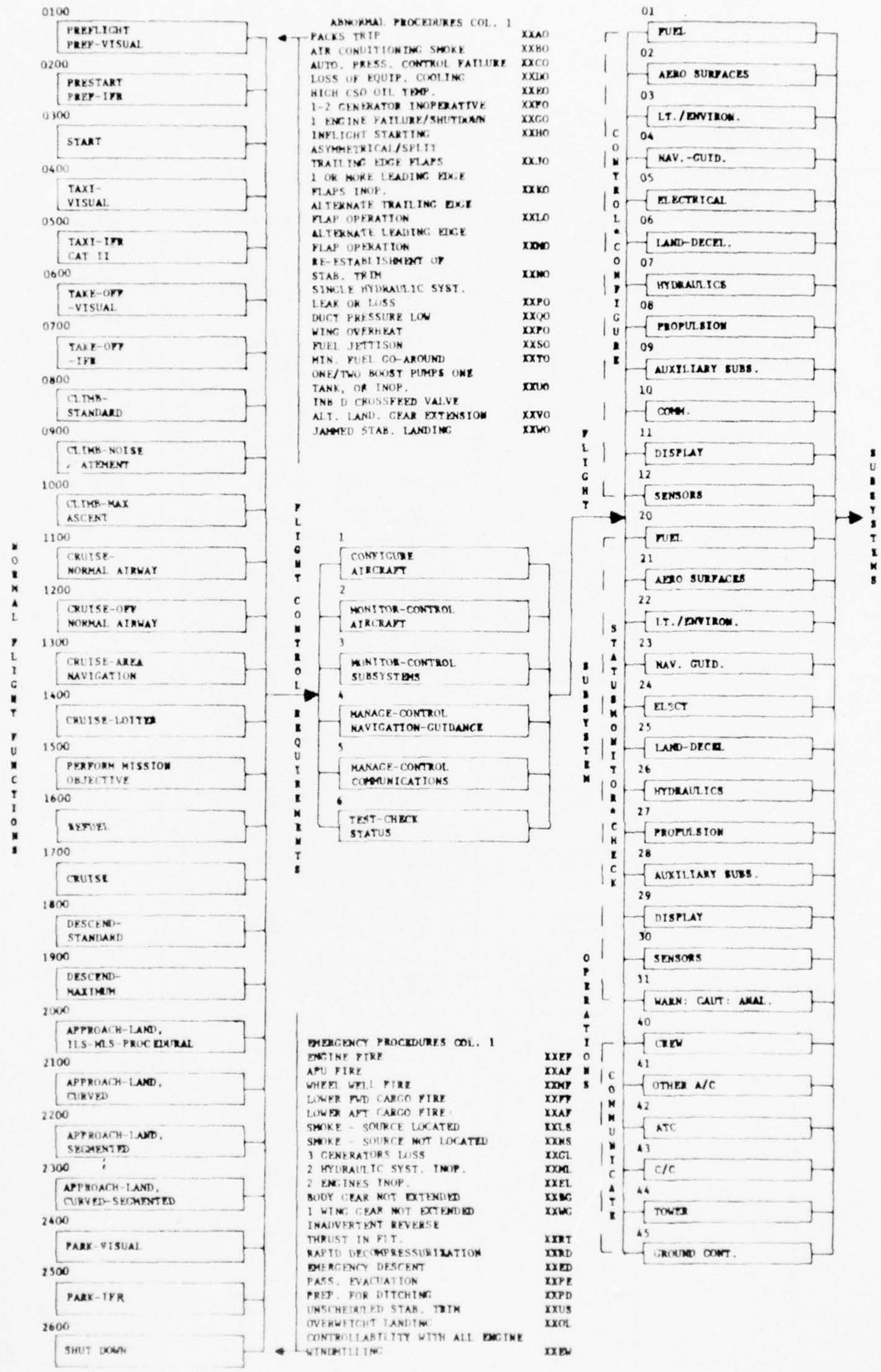


FIGURE 2.2-19: EQUIPMENT DATA ORGANIZATION CONCEPT

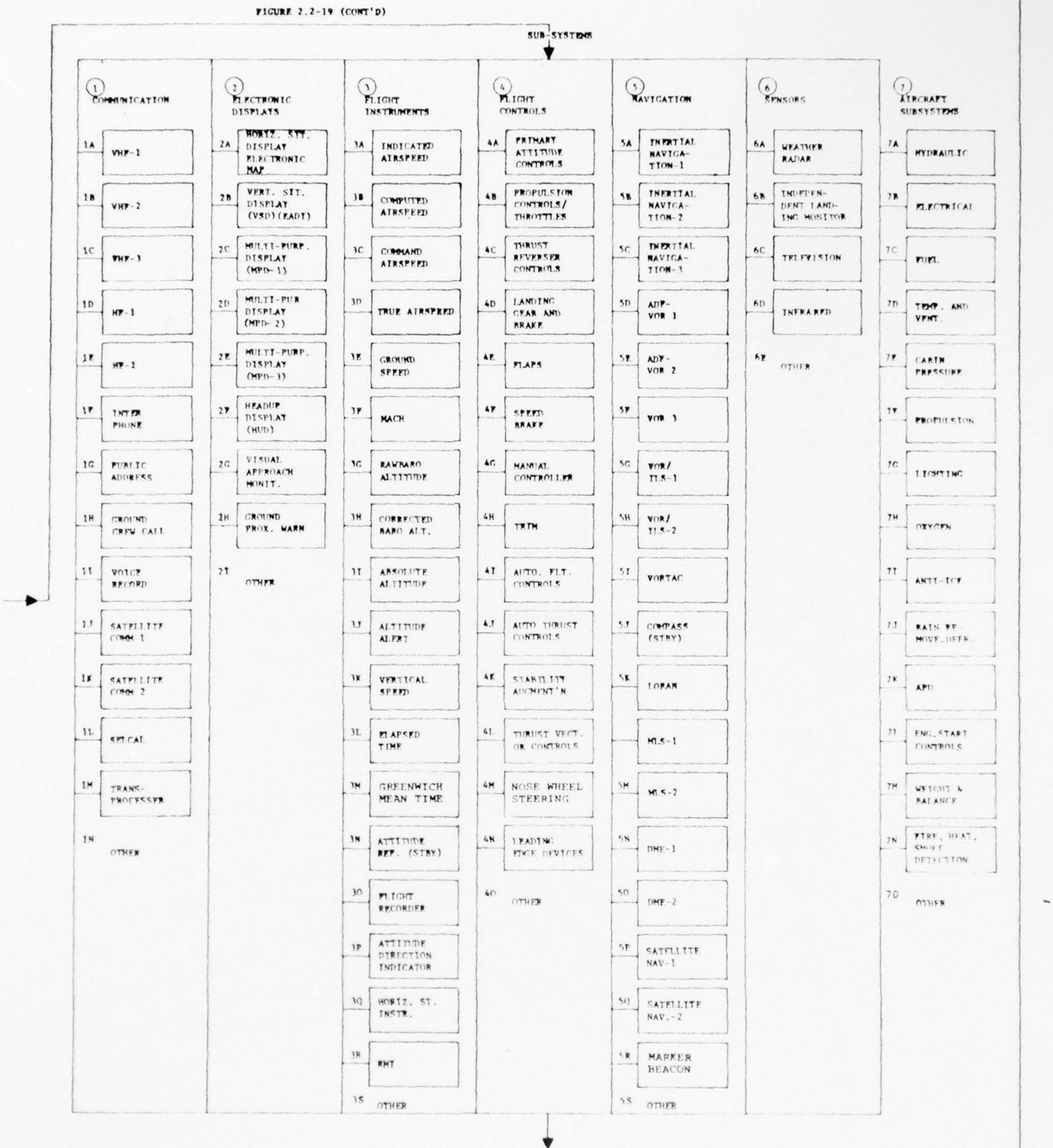


FIGURE 2.2-19 (CONTINUED): EQUIPMENT DATA ORGANIZATION CONCEPT

AD-A040 478 BOEING AEROSPACE CO SEATTLE WASH RESEARCH AND ENGINE--ETC F/G 5/5
HUMAN FACTORS ENGINEERING ANALYTIC PROCESS DEFINITION AND CRITE--ETC(U)
JUN 75 D L PARKS, W E SPRINGER N62269-74-C-0693

UNCLASSIFIED D180-18750-1 NL

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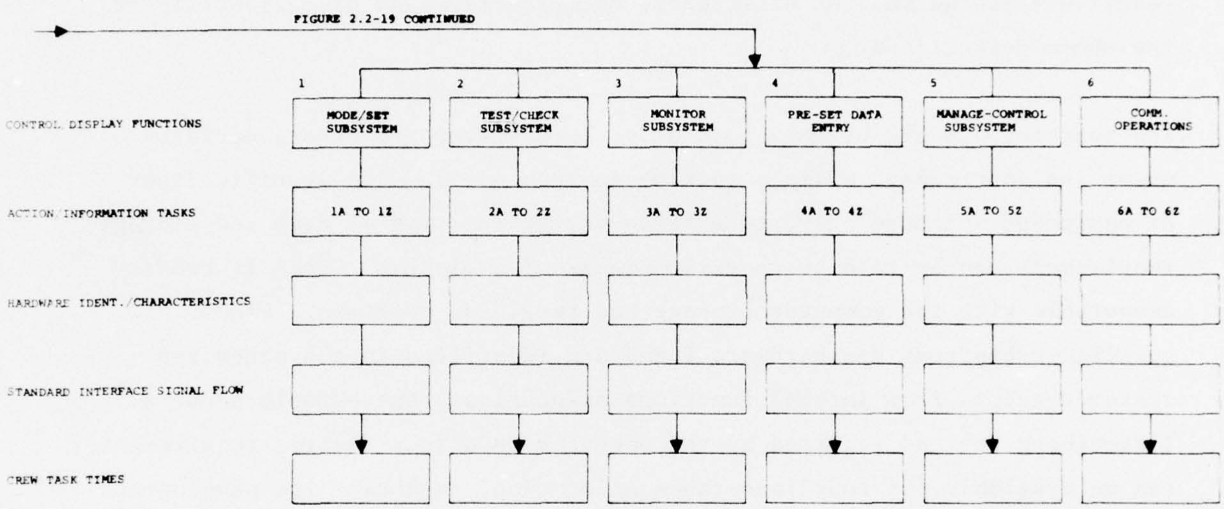

FIGURE 2.2-19 (CONTINUED): EQUIPMENT DATA ORGANIZATION CONCEPT

2.2.2.4 (Continued)

TASK PERFORMANCE DATA ELEMENTS

The task information currently being used for systems development and the CAFES submodel assessments are generally derived from "expert" knowledge, (including knowledge of data sources), rather than being drawn from a storage bank of information. The ability to further automate task allocation and workload analysis requires the inclusion of stored information about human movement, operation, manipulation, cognition, processing and reactive times as well as efficiency, and effectiveness or reliability of the above definitions.

The operator, in his primary role as an information processor, decision maker and controller, will be working in conjunction with specific items of equipment. Accordingly, to a large extent the type of data and storage requirement can be tied to specific pieces of equipment. This is readily compatible with the computer storage and retrieval programs. Since specific subsystems and hardware items are identified in a synthesized system concept from initial functions allocations, the associated data (describing actions required by the operator to effect desired requirements) can be available for functions-tasks allocation, task timeline development and workload analyses.

The task data tied to a specific mission requirement, subsystem or piece of equipment can include:

1. function(s) performed or augmented by use of equipment,
2. function criticality,
3. actions required, controls to be actuated, or manipulations to be performed,
4. type of information, displays to be viewed or manner of information feedback provided for each manipulation,
5. more commonly used general location and/or orientation of equipment, to define the degree of difficulty associated with viewing and reaching of the controls and/or displays,
6. channels of activity necessary to absorb and/or acknowledge information displayed, as well as to input control actions,

2.2.2.4 (Continued)

7. type and time duration of required activities,
8. typical response characteristics: frequency, range, consistency,
9. interdependency of equipment functioning, with associated components and priorities of operation among equipment functions.

Other task data characteristics of interest include a measure of the adequacy, rapidity and accuracy versus type of operation (e.g., a measure of effectiveness, or of probability of successful completion of the activity within a specified time period). These types of data contribute to evaluation of the variabilities between crewstation configurations and the effects of varying combinations and arrangements of controls and displays. However, there are limitations and precautions to be observed in establishing task data characteristics that are commonly and directly comparable for all operations. Much of the data that are available are useable in the context of being qualified and applied with sound professional expertise, but frequently lack the general utility that would accrue with the ability to perform more complex mathematical operations, e.g. additive or multiplicative uses. Considerable progress has been made in such data areas as human performance reliability, task performance time and accuracy. These data can be applied meaningfully to permit reasonable comparisons of predicted effectiveness between system concepts, and to produce preliminary appraisals for a given system concept. As this data base is refined and improved through use and validation, significant improvements will accrue in both the quality of predictions and ultimate operational results.

CREWSTATION HARDWARE IMPLEMENTATION-LAYOUT DATA

The development of functional flow block diagrams to the lower levels of indenture begins to isolate candidate equipment components for various phases of the mission. The identification of candidate equipment by phase then leads to an evaluation across the entire mission and a trade-off as to the pragmatic arrangement which appears most feasible.

The information specifically concerned with the equipment, in addition to function(s) capable of being performed, include the following physical characteristics:

2.2.2.4 (Continued)

- o dimensions of package
- o display/control types, features, quantities
- o display/control dimensions
- o force required for manipulation
- o type of movements necessary
- o means to verify control position/actuation
- o power input type/quantity
- o related equipment necessary for operation, input signal or output processing.

Such information is definable for storage and retrieval in an information system. Prior layout concepts, trade-off qualifications and criticalities, and such considerations as representative frequency of use are definable for storage and retrieval. Additional considerations such as unique requirements for a given display or control related to mission phase (or peculiar task data, characteristics or constraints related to a given item) could also be stored for easier use and retrieval. In short, there is a strong case for an information system that organizes, stores and makes available such data, with appropriate qualifications, for readier use.

2.3 COMPUTER AIDED FUNCTION-ALLOCATION EVALUATION SYSTEM (CAFES) CONCEPT SUMMARY, CHARACTERISTICS, OUTPUTS AND USES

2.3.1 General

CAFES development is intended to be used to support, enhance and expedite the HFE processes described in preceding sections. The objective is to provide for improved and timely results and more effective use of such results in management decision making during a system development program. This objective is to be accomplished by computer technology to facilitate organization, processing and use of data, and to assure early, systematic and comprehensive treatment of all crew related parameters that need to be considered in system programs. Representative system areas where such applications are expected to be beneficial include:

1. Improved development, evaluation and confirmation of crew station configurations
2. Improved weapon system performance through improved crew performance
3. Higher probability of mission success
4. Improved manpower utilization
5. Reduced training costs
6. Improved safety through fewer errors and accidents in system operations
7. Improved crew systems performance in airborne systems

CAFES use for HFE efforts during system development will offer many technological advantages for the analyst. It will help to develop, record and provide consistent and comprehensive analysis data relating to present and future systems developments. It will provide a record of on-going development decisions and rationale during a given program, i.e., a recording of crew related information for a given system, from early requirements analyses through design, development, test and evaluation, and training systems development. It will facilitate data access, integration, interpretation and use in program support activities. It will enhance ability to make effective judgements while offloading routine, elementary and tedious analytic operations. It will provide a tool for evaluating effectiveness of decisions prior to implementation. Finally, it will help to identify data gaps and needed man-machine research to support development.

2.3.1 (Continued)

In effect, CAFES provides computer techniques to structure, control and evaluate crew systems aspects of a developing system. It provides for maximum use of data from experience, research and other programs to provide early analytic results. It also provides for improved continuity in the parametric trade-offs of man-machine interfaces necessary for most effective crew related provisions in a comprehensive system development. Most specifically, CAFES extends the use of computer technology for HFE application through:

- Application of computer techniques to assist in requirements definition, function allocation, workload evaluation, preliminary crew station design, and evaluation and other human engineering trade-off studies and activities which have been accomplished by manual means.
- Integration of the computer methods to provide efficient and comprehensive capability for more extensive analysis of man-machine interface interactions, to provide much of the needed human factors data for systems development, and to provide critical trade-decision data as needed.

However, CAFES cannot work effectively without guidance based on the expertise, skill, and professional judgements of a knowledgeable human factors engineer. As in more traditional methods, he must make numerous decisions based on interpretation of system requirements, specifications and applications of qualitative as well as quantitative information. This will continue to be the case with the type of HFE information and data used in the analytic process, and the type of trade-off decisions required (e.g., relating to crew size, display requirements and features, life support variations and resolution of conflicting data). The computerized models can only assist the process by retrieving, processing, organizing and/or presenting data as required. They can also be used to evaluate the system impact of alternative trade-off decisions.

2.3.1 (Continued)

Since CAFES requires involvement of the HFE analyst, effective interface provisions are continually emphasized. English language formatting is used for easier use and interpretation. Additionally, model concept development is now to the point where added attention to simplified input-output formatting is timely, to minimize efforts to input, access and use the models. One of the goals for the present is to clarify areas where related refinements are desirable.

In summary, the CAFES concept development and application is based on a synthesis of (1) crew system methodologies, (2) applicable HFE data derived from a diverse set of sources, (3) management by the HFE analyst as the control element, evaluator and decision-maker during CAFES operation, and (4) a computerized data management system coupled with models supporting typical processes to store, retrieve and manipulate data, procedures and programs.

2.3.2 Submodel Definition

For the purpose of permitting comparison of various CAFES operations with the baseline methodological developments of earlier discussions, summaries of the various submodels follow. The summaries provide a CAFES orientation for the reader who is not familiar with the program, and provide highlights of relevant features correlated with the baseline process for the reader who is familiar with the program. Summaries are heavily based on abstracting and organizing data from published documentation. More detailed descriptions are available in technical reports published during development of the submodels. These reports include references 1 through 18 for the Crewstation Geometry Evaluation (CGE) submodel, and 19 through 29 for the Data Management System (DMS), the Function Allocation Model (FAM), the Workload Assessment Model (WAM), the Computer Aided Design of Crew Stations Model (CAD), and the Human Operator Simulator (HOS). Other references (30 through 46) contain background information relevant to submodel development or to related methods, concepts and applications.

The computer aids are a set of submodels working in conjunction with a data-information management system. Each submodel may be used individually or in combination with one or more of the other submodels, depending upon the requirements for data and analysis at any point in the research, development, test and evaluation cycle. The modular construction of CAFES will provide flexibility for inclusion of the nyriad of parameters that may have to be integrated for meaningful definition and evaluation of the human's role in a system development.

The CAFES submodels are identified by name below:

1. Data Management System (DMS)
2. Function Allocation Model (FAM)
3. Workload Assessment Model (WAM)
4. Computer-Aided Crew Station Design Model (CAD)
5. Crew Station Geometry Evaluation Model (CGE)
6. Human Operator Simulation Model (HOS)

2.3.2 (Continued)

Each of these CAFES components is described in later sections, together with their development status, inputs, outputs, general purpose, and utility. Figure 2.3-1 together with Tables 2.3-1 and -2 provide an introductory overview of these subjects.

The design of the system provides the user with necessary computer program visibility and essential elements of control for effective use and management. Several related objectives are involved in the intent to provide a tool useable by the human factors engineering community. These objectives are to provide for:

1. Broad applicability in producing data for human factors engineering across the full spectrum of man-machine systems, research and development activities; and operational problem solving. In addition to system design and operations, CAFES will also be applicable to training, maintenance, job-aids, and other functional regimes where human performance is critical to system effectiveness. For example, CAFES can be applied to training in several respects:

    o Definition of training requirements for crews of a new system (e.g., task procedures, proficiency levels, task allocations, etc.).
    o Man-machine allocation within a training system (e.g., trade between instruction by humans and machine-assisted training aids).
    o Workload analysis for training procedure development (e.g., for degraded mode training).
    o Add to design of training devices (e.g., instructor consoles).
    o Evaluation of training programs by comparison oftrained skills versus required skills, trained procedures versus optimum procedures, etc.

2. Visibility and traceability for quick identification of the factors having greatest effect on system performance and underlying assumptions which heavily influence CAFES estimates of system performance.

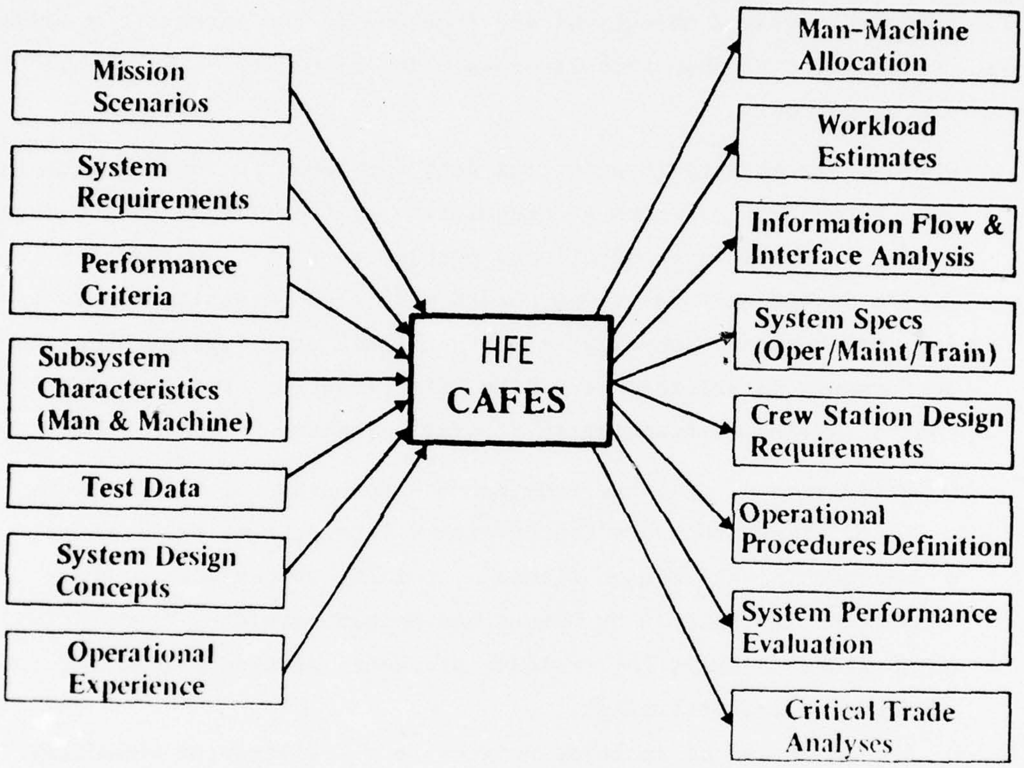

FIGURE 2.3-1: CAFES INPUTS/OUTPUTS

TABLE 2.3-1 CAFES COMPUTER AIDS

NAME	PURPOSE
Data Management System (DMS)	Provide a highly flexible data storage/retrieval system for the full range of HFE data needs; assure ready orderly use and updating.
Function Allocation Model (FAM)	Process/test man-machine task allocation solution sets for each alternative equipment selections per mission requirements.
Workload Assessment Model (WAM)	Identify and evaluate tasks, procedures, frequency and time of display/control usage on composite mission profiles to verify overall feasibility of specific man-machine combinations.
Computer Aided Crewstation Design Model (CAD)	Assist in preliminary crewstation configuration layout - use FAM and WAM results to systematically structure station configuration according to design requirements/constraints derived by FAM and WAM.
Crewstation Geometry Evaluation Model (CGE)	Identify potential physical incompatibilities between the proposed crewstation and standard anthropometric and ergometric data.
Human Operator Simulation (HOS)	Provide a generalized computer-driver model of a human being in a goal-oriented task processing environment.

TABLE 2.3-2: CAFES CAPABILITIES

FUNCTION ALLOCATION (FAM)	o BEST CREW SIZE o BEST AUTOMATION LEVEL o OPTIMUM TASK ALLOCATION
WORKLOAD ASSESSMENT (WAM)	o VERIFICATION OF ALLOCATIONS o DETAILED PROCEDURE ANALYSES o OPTIMUM CREW STATION DESIGN
COMPUTED AIDED CREWSTATION DESIGN (CAD)	o FEASIBLE STATION LAYOUTS o SENSITIVITY TO REQUIREMENTS, CONSTRAINTS, CRITERIA
CREWSTATION GEOMETRY EVALUATION (CGE)	o VERIFICATION OF DETAILED CONFIGURATIONS o TASK TIME ESTIMATES
HUMAN OPERATOR SIMULATION (HOS)	o HUMAN PERFORMANCE ESTIMATES o SENSITIVITY TO BEHAVIORAL FACTORS, OPERATING ENVIRONMENTS, ETC.

2.3.2 (Continued)

3. Consistency with state of the art in human factors methodology and data but with growth potential to incorporate new techniques and improved data.
4. Flexibility to evaluate impact of changes in analysis conditions; for example, degraded modes of operation, mission scenario changes, etc.
5. Capability for human factors personnel to interact with CAFES computer systems such that professional judgement can be aided by the computed results.
6. Capability for quick summary results for studies of "hot" problems requiring quick turnaround, or can be employed in long-term, in-depth studies involving extensive detail and integration.

The application of the CAFES submodels in human engineering will be discussed under the section for each. However, the greatest utility of CAFES is in the integrated use of submodels for interactive use of information or to produce any specific output data and analysis required during new systems development. An example of model relationships is illustrated in Figure 2.3-2; interactive application of these models can help to produce all the various CAFES results that were summarized in Figure 2.3-1.

Primary outputs of each model are shown in Figure 2.3-2. Major feedback loops are also indicated. For example, the workload analysis by the Workload Assessment Model may suggest a re-exercise of the Function Allocation Model to evaluate different allocation versions, and outputs from Crewstation Geometry Evaluation Model may suggest a change in basic configuration to be run on the Computer Aided Crewstation Design Model. Consequently, the integrated capability of the CAFES method will be fully realized when all submodels are completed and interrelated.

CAFES can be applied at alternative levels of detail, and would normally be applied iteratively throughout the system development cycle. System detail is usually sketchy during early concept formulation, but CAFES can still be applied at a gross level or, with numerous assumptions, at a detailed level. As system development progresses, the ratio of system detail to system assumptions improves considerably and CAFES analysis can be carried to much greater detail. Operation of the various CAFES submodels is not

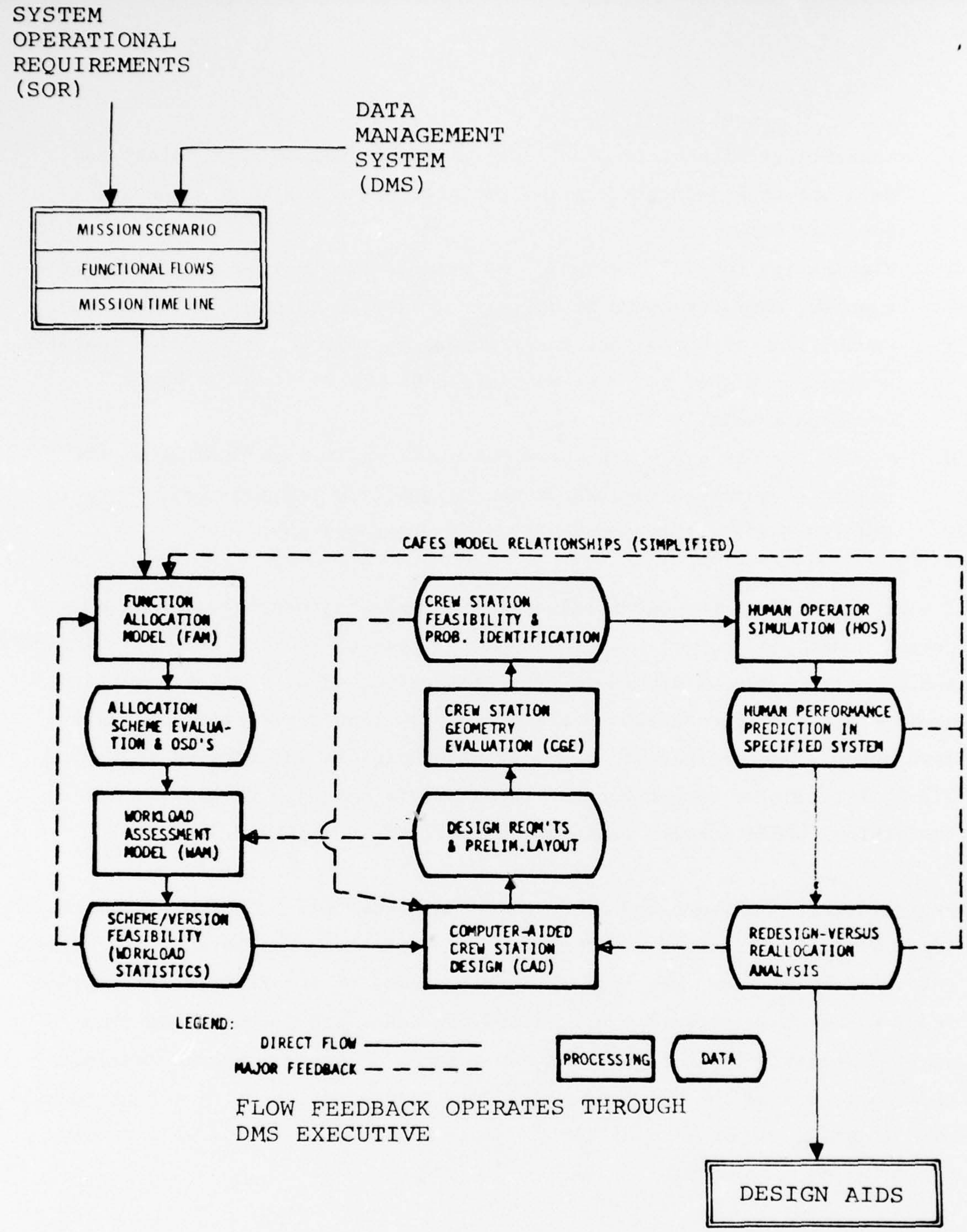

FIGURE 2.3-2: CAFES MODEL RELATIONSHIPS

2.3.2 (Continued)

constrained by level of detail. The Function Allocation Model, the Workload Assessment Model, etc., can operate at any level throughout the range from top level functions to very specific subtasks. The second aspect of CAFES applications, iterative operations, refers to the interactive nature of the different submodels, and the potential for analysis refinement through multiple runs of each submodel based on dynamic changes in results from the other CAFES submodels. Although most effective use of CAFES will include the sequential application of all submodels, each of the submodels may also be used independently, and provide data specifically for a given problem.

Continued analysis and development of methods for applying CAFES to Navy systems development is required to assure an evolution of maximum practicality and useability. CAFES applications to various Navy missions, systems, and development activities are illustrated in Figure 2.3-3. The general flow for the CAFES application analysis is illustrated in Figure 2.3-4. For any system, the types of data and analyses that can be produced or supported by CAFES include:

1. Man-machine function allocation.
2. Mission task analysis.
3. Information requirements.
4. Control-display listing.
5. Crew-loading timeline assessment.
6. Crewstation configuration requirements/constraints listing.
7. Crewstation geometry evaluation.
8. Operational procedures specification/evaluation.
9. Operator/system performance.
10. Crewstation design-related trade-off analysis.

Upon completion of CAFES development a user-oriented capability will be available for systematically structuring and evaluating those parameters having a direct impact on crew systems operations. The information to be generated through CAFES utilization will be in context with that of other systems development activities at equivalent points in the development cycle.

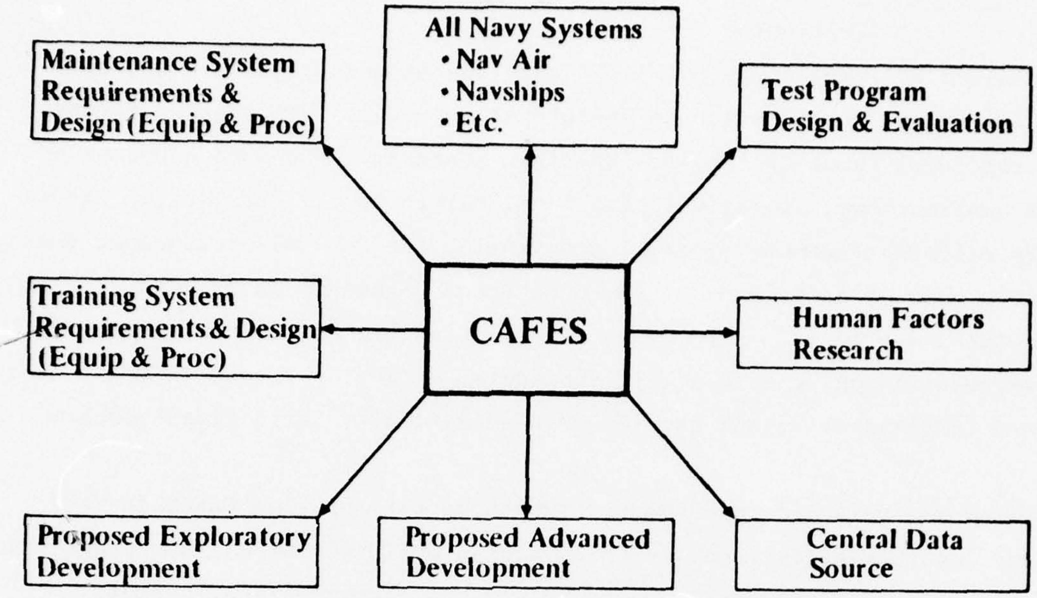

FIGURE 2.3-3: CAFES APPLICATIONS

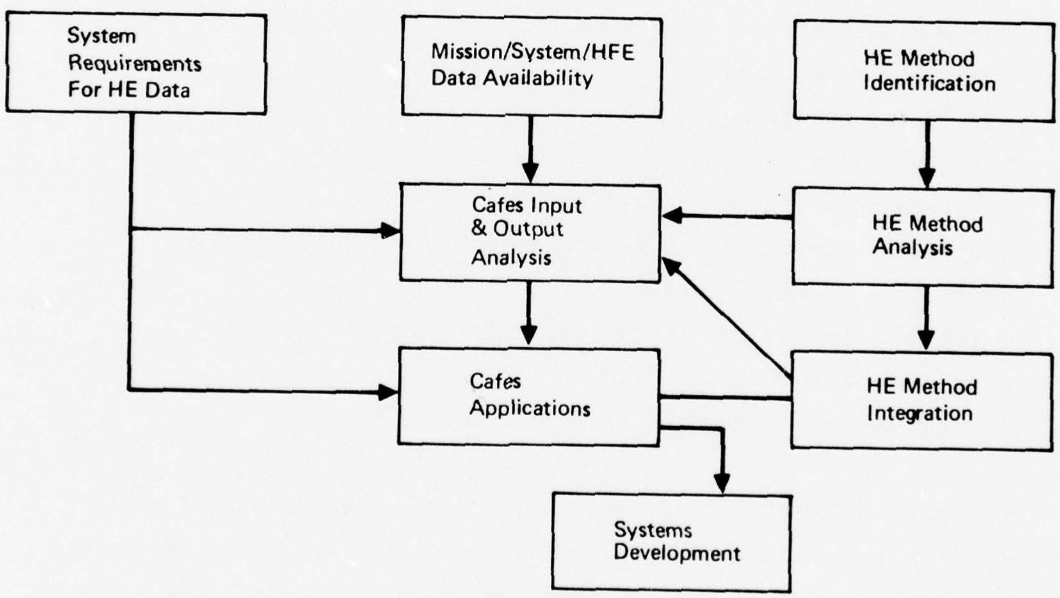

FIGURE 2.3-4: CAFES APPLICATIONS ANALYSIS

2.3.2 (Continued)

Submodels will be applicable to human factors tasks throughout the development and operational cycle of Navy man-machine systems. From early identification of crew system requirements during the conceptual phase through system evaluation during fleet operations, CAFES will be exercised repeatedly to assist requirements analyses, test and systems design, procedures development, and training and maintenance systems development.

Following discussions summarize the various models. In order to provide a conceptual framework for present discussion while minimizing redundancy with data which has been published, the approach for the discussions was to

- o Briefly summarize the submodel concept
- o Outline the requirements specification
- o Produce such commentary as are relevant and necessary to
    - o Relate submodel uses to the baseline methodology developed earlier
    - o Identify desirable refinements

For more detailed information on submodel design, features and operations, the reader is referred to appropriate documents in the reference list.

2.3.3 Data Management System (DMS)

2.3.3.1 General Concept

The Data Management System (DMS) provides two roles in the CAFES concept. (1) It provides a storage capability for all HFE endeavors, encompassing a variety of different structures, hierarchy and data forms. (2) It provides the collection of instructions and routines to manipulate the data for each of the submodels and (3) It provides the interfaces between the computer submodels.

The human factors engineer interfaces with the DMS in several ways.

1. to input new data
2. to modify data in storage
3. to delete stored data
4. to instruct CAFES submodel execution
5. to instruct report preparation
6. to receive data reports

The type of information required for the vast and varied human factors task requires an extensive storage system. Accordingly, cost effectiveness must be considered for the data entry taxonomy. The system must be flexible and yet manageable to minimize the cost of inputting, storing, and retrieving the initial information as well as minimizing the cost of the report summary data package. Also, it must provide for simple operations to update, replace, modify, augment and otherwise manipulate the data collection. In addition, the data management system must allow for communication between the generater of data and the user of the data, and with the set of computer submodels which operate with the data.

The data management system is a set of instructions which work from initial instructions from the human factors analyst to compile and allocate data in the format necessary for direct data access or for use by each one of the CAFES submodels. The results of manipulation by each submodel is both presented and stored, with the initial input information, for retrieval in report form at a later time. The data are also available for transformation as input data to another submodel. Figure 2.3-5 illustrates the interactions of the various functions performed by the data management system.

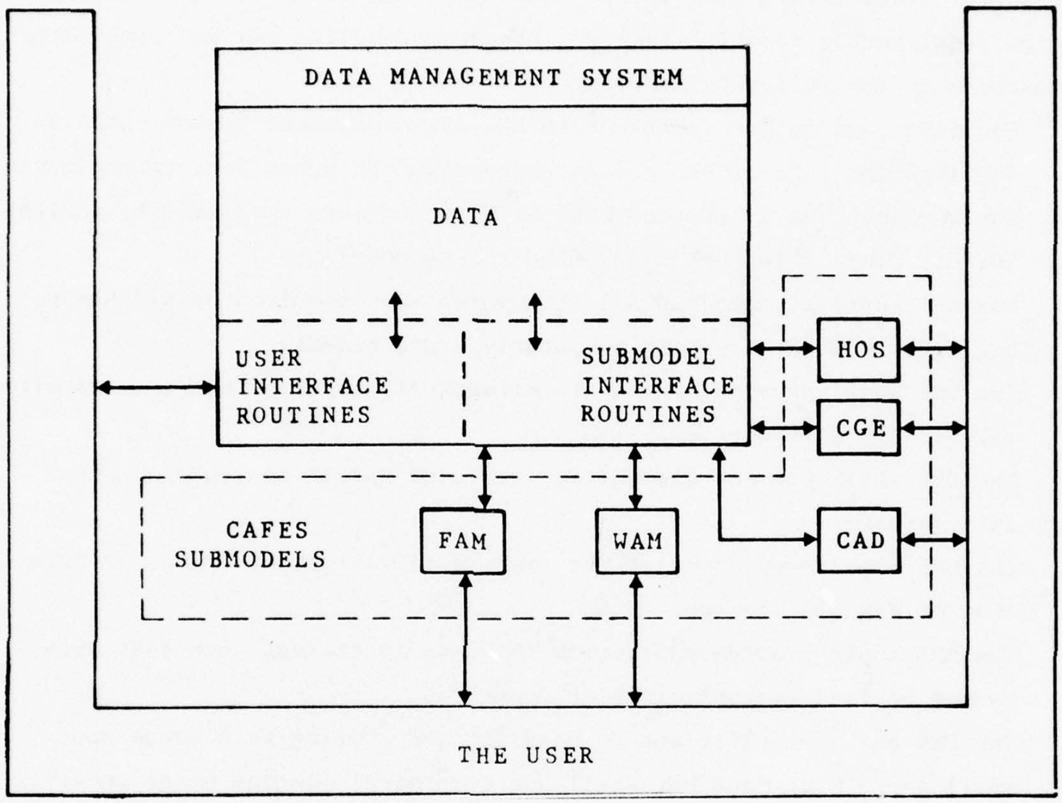

FIGURE 2.3-5: DATA MANAGEMENT SYSTEM INTERACTIONS

2.3.3.2 Data Management System Requirements Specification

This dual role of user interface and submodel interface places special demands on the data management system in terms of accommodating both an easy-to-use data format for the human factors engineer and an efficient data format for transferring data to and from the computer submodels. Specific design requirements to which the data management system was developed are summarized in the following listing:

- The input and output formats for the data management system shall be designed for ease of use and interpretation by human factors engineers.
- The DMS shall be consistent with CAFES objectives and shall be designed for efficient interface with all CAFES submodels.
- The DMS shall accommodate all data parameters required by all human engineering methods - both computerized and manual.
- The DMS shall provide options to selectively input or output data with easy-to-use instructions.
- The DMS shall provide flexibility for user specification of output data formats.
- The DMS shall provide means for easy modification, addition, or deletion of data in storage.
- The DMS shall provide safeguards for data in storage such that data cannot be inadvertently lost or destroyed.
- The DMS shall be efficient in handling and storing both large and small amounts of data but shall use economical storage means whenever possible.
- The detailed structure of the DMS shall be designed for growth potential to efficiently accommodate new data parameters and data formats as they become available (e.g.: when CAFES submodels are added or modified).
- The DMS shall facilitate high commonality of data parameters between the various submodels and shall be internally consistent in units, constants, nomenclature, etc.
- The DMS shall provide error messages and diagnostics for trouble shooting purposes and shall be "fail safe" by supplying standard data for submodel execution in the event a user fails to specify required input data. (This event shall be reported to the user.)

2.3.3.3 Data Management System Relationship to Baseline Methodology

Numerous candidate areas for DMS provision of data were identified in the section on baseline methodology. Two major distinctions existed. The first was between that initial information and data base which was necessary to organize information prior to initiating application of any of the various submodels. The second was that information and data used by each submodel. For convenience of discussion, the initial data base will be treated here. Information relevant to each submodel will be discussed in the appropriate submodel discussion.

Four major preparatory efforts were indicated in the baseline methodology: composite mission requirements, functional flows with action-information requirements, qualitative and quantitative task data, and man-machine interface equipment data reflecting both related tasks and hardware characteristics. For supporting such efforts, DMS is readily compatible with accepting and producing quantitative data. It can operate effectively with terse statements such as are entered in functional flows. It can list references for cases where analyst retrieval and review is appropriate. However, operation becomes combersome when textual material is desired (e.g., mission scenarios - paragraph 2.2.1.2; or for information-data qualifications, and pilot commentary - Figure 2.2-14). Such unwieldy characteristics can be somewhat reduced if text is reduced to terse, indentured outline format.

Accordingly, information that could be stored includes:

Mission Requirements

- o Outline of system operational requirements
- o Outline of mission scenario
- o Mission profile data

Functional Flows

- o System common functions (all aircraft)
- o System type functions (e.g., fighter)
- o Mission peculiar functions

2.3.3.3 (Continued)

Task Data

- o Task types
- o Quantitative data (e.g., reliability; time; accuracy)
- o Terse outline summaries of qualitative data (pilot comments; trade-off precautions)
- o Reference topics or sources

Man-Machine Interface Equipment Data

- o Hardware data (physical features; performance characteristics)
- o Related tasks and task data

Other Data

- o Human anthropometry
- o Life support data

The areas identified above are preliminary, but offer a framework for structuring major topical areas relevant to systems development in the DMS. More extensive development of a manual baseline for a total system concept is desirable in order to more clearly isolate and designate a taxonomy structure for each of the areas. Such development will require considerable care and attention to detail in order to maintain cost effective operations of the DMS.

An added, very major advantage to producing such a detailed development (including such features as detailed functional flow block diagrams and mission time lines) is the carryover knowledge to similar weapons systems. Each generic weapons system, such as a fighter aircraft, has common operational requirements. The commonality of the phase activities such as pre-flight, taxi, take-off, climb, cruise, etc., makes it unnecessary to construct an entirely new set of functional flows. The functional flow block diagrams will be capable of covering most of the operational requirements for each new systems development. The individual equipment components may vary somewhat and mission specific activities will be unique to a specific weapons system, but the vast majority of tasks, types of subsystem components and activities carried out by the crewman will be identical to previous systems or sufficiently similar to allow rapid assessment of areas unique to the new weapons system.

2.3.4 Function Allocation Model (FAM)

2.3.4.1 Function Allocation Model Concept

The Function Allocation Model (FAM) concept is among the most complicated of the CAFES submodels. Accordingly, it will be summarized in more detail than the others.

The FAM and all other CAFES submodels requires the human factors engineering analyst to obtain detailed operational requirements, mission scenarios, functional flow block diagrams, and mission time lines. This detail is necessary before comprehensive trade-offs of functions and tasks are possible. The initial production of the necessary input data requires concentrated, dedicated effort on the part of the human factors engineering analyst. However, processing via the Function Allocation Model is rapid and requires minimal time. Following the computer analysis, the analyst may rapidly progress the examination of a large number of alternate solutions.

The FAM is a CAFES submodel used to assist the human factors engineering analyst to: identify and allocate the tasks and functions to be assigned to each crew-member, identify required equipment, and evaluate selected man/machine combinations. The human factors analyst must ultimately decide whether a man is to perform a given function or whether equipment must be provided to take care of these tasks. In certain instances, existing equipment is specified for use, and it then becomes necessary for the human factors analyst to verify that functions, tasks, mission objectives and operational requirements can be satisfied. Once this requirement is satisfied, it is necessary to devise an optimum arrangement of tasks to maximize mission effectiveness and reliability.

General Functions Allocation Considerations

The allocation of functions between men and machines is an inextricable process of system design, development test, and evaluation. As such, function allocation is a multidiscipline endeavor in which hardware and software designers work in cooperation with the human factors specialist to design the optimum man-machine system. This muitidisciplinary structure has resulted in the development of numerous techniques for evaluating crew-workstations, man's functioning in the workstation, and system performance.

2.3.4.1 (Continued)

Text books, technical reports, and human factors engineering manuals adequately discuss function allocation techniques. They provide little help in defining specific procedures for the process of function allocation. The process of allocation generally falls under the category of "professional qualitative judgment." An excellent procedure to follow in performance of this "judgment" is as follows:

- Listing and analyzing of system functions
- Identifying plausible candidates for function implementation
- Identifying criteria for function allocation
- Analyzing data related to above criteria
- Preparing of a comparison matrix that exhibits all candidates versus the selected criteria.
- Performing weighted, quantified evaluations
- Selecting and justifying of the allocation
- Re-evaluating and periodically updating functions allocated commensurate with availability of more detailed system development data.

A traditional allocation method is "allocating functions on the basis of what man does best and what machine does best." There are several guidelines that should be considered when working with this allocation method:

- Allocating functions one at a time to either man or machine can lead to a solution for a full set of mission functions if done correctly.
- Man and machine are interactive in many functions of man-machine systems.
- Function allocation is not necessarily always tied to which subsystems give best results, that is, particular situations may demand "non-optimum" allocations because specific equipment must be employed.
- The concept implies that once allocations are made they become permanent assignments, yet the optimum solution may provide flexibility for changing allocations to adapt to changing situations.

2.3.4.1 (Continued)

Another task is the choice of allocation criteria. It must be determined which are more important, and by what relative weighting? Examples of performance criteria are task execution time and accuracy of task performance. The human factors engineer is responsible for establishing quantitative values for these criteria. But aside from these primary criteria, there are a host of secondary criteria which can significantly affect allocation decisions. These other criteria, many qualitative, must be input from a source outside human factors technology. Examples of these criteria are:

1. Cost (e.g., procurement; operating)
2. Weight
3. Development time
4. Development risk
5. Safety
6. Maintainability
7. System effectiveness (e.g., targets destroyed)
8. Physical volume, size limits
9. Survivability

The application of criteria for allocating functions provides a basis for determining how different allocations might result in a different system performance or cost-effectiveness. However, overall system performance is related to (1) how system performance is affected by human performance, and (2) how human performance is affected by system, mission, or environmental factors.

FAM Description

The FAM offers a method for evaluating the consequences of allocating functions to alternative man-equipment combinations. Basic inputs to the model, as well as to other CAFES models are from the mission scenario, function and task analysis as shown in Figure 2.3-6. This consists of a list of non-allocated operational functions for a prescribed mission and a prescribed

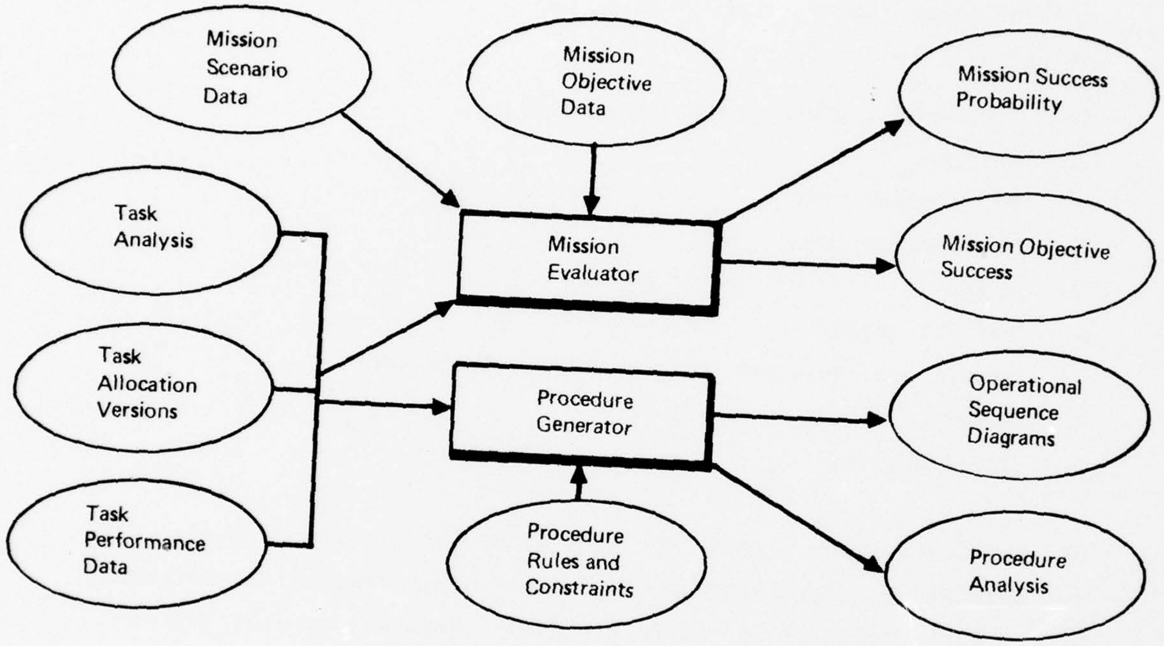

Figure 2.3-6: *Function Allocation Model (FAM) Input--Output Diagram*

2.3.4.1 (Continued)

system scheme. The mission function list could result from development of a detailed functional flow block diagram or could simply be a list of high level functions, depending on how far definitive system development has progressed. The function list is an essential ingredient in function allocation, as mission functions must first be identified and analyzed before they can be allocated to man and/or machine. To accomplish this, FAM operates with six major data groupings:

1. Task data
2. Mission scenario data
3. Tables and constants
4. Mission objectives
5. Mission events
6. Allocation versions

The FAM is composed of two main data processing blocks: The Mission Evaluator and the Procedure Generator. The Mission Evaluator computes mission success probabilities for different task allocation candidates, and the Procedure Generator produces a task sequence based on task allocations and procedural rules and constraints. The Mission Evaluator is used to rank order all the different variations in task allocation that are under consideration, whereas the Procedure Generator is used to do a refined analysis (e.g., Operational Sequence Diagrams) for allocation candidates that are selected as most promising. Primary inputs and outputs of these two main processors are illustrated in Figure 2.3-6. Each data entry item (task input data) will be defined first. When this is completed for all items, their uses in producing the desired FAM results will then be described.

MISSION EVALUATOR

The Mission Evaluator uses mission scenario task data in the form of a tabular list of mission tasks, number of task occurrences, start time for each occurrence and time duration for each occurrence - in effect, a task time list. If desired by the HFE analyst, it may use task load ratings (Table 2.3-3) as a time stress modifier to scale task execution times or to prioritize tasks. It operates with specific objectives, such as the

TABLE 2.3-3 TASK LOAD RATING SCHEDULE

Task Modifier	Rating Levels
precision (accuracy criticality)	0....no precision required 1....moderate care 2....close as possible
concentration (channel dedication)	0....little or none required 1....moderate attention 2....very close attention
reliability (performance criticality)	0....usually not mission critical 1....success important (repeat to make it right) 2....must be right first time
continuity (non-interruptibility)	0....interruptions allowed usually 1....interruptions inadvisable 2....interruptions not allowed
mission priority (timing criticality)	0....can be deferred usually 1....delay can cause mission failure 2....delay not allowed

2.3.4.1 (Continued)

"intermediate" mission objectives: (a) threat detection and suppression; (b) navigation to target vicinity; (c) target acquisition; (d) weapon delivery, or (e) damage assessment. A conceptual framework for one such objective, target detection, with five detection modes and both parallel and sequential operations, is illustrated in Figure 2.3-7. System task reliabilities for each task in the sequence are computed for both operator and equipment, on the basis of which subsystems are allocated to the task, their type of parallel-redundant relationships and task performance reliabilities for both operator and equipment. Examples of allocations that might be evaluated are illustrated in Table 2.3-4. In the mission evaluator, variable weighting factors for critical tasks (e.g., target tracking vs. navigation) can be used if desired. Probability of success for the intermediate mission objective is then computed by standard reliability methods, e.g., following the rules for parallel, redundant or sequential reliabilities. Overall mission success can be similarly estimated by accumulating reliabilities for performance of "intermediate" mission objectives.

Task allocation versions are created by integrating a concept for the tasks, the operators and the hardware subsystems under consideration. This combining process results in candidate crew member and equipment assignments for the specified mission tasks. Included in the task allocation is a definition of how tasks are assigned in cases where two or more subsystems are allocated to the same task. These are cases of redundant assignment to improve overall task reliability.

The computer can accommodate a large number of different allocations, therefore there is no necessity to defend any particular version as the best choice prior to Function Allocation Model execution. Traditionally the human factors engineer is asked to derive one best choice which is difficult to defend on a quantitative basis. Through quantitative allocation analysis, the human factors engineer is relatively free in his selection of candidate allocation versions and to exercise professional judgment in both his selection of practical candidates and his comparative evaluation of quantitative results.

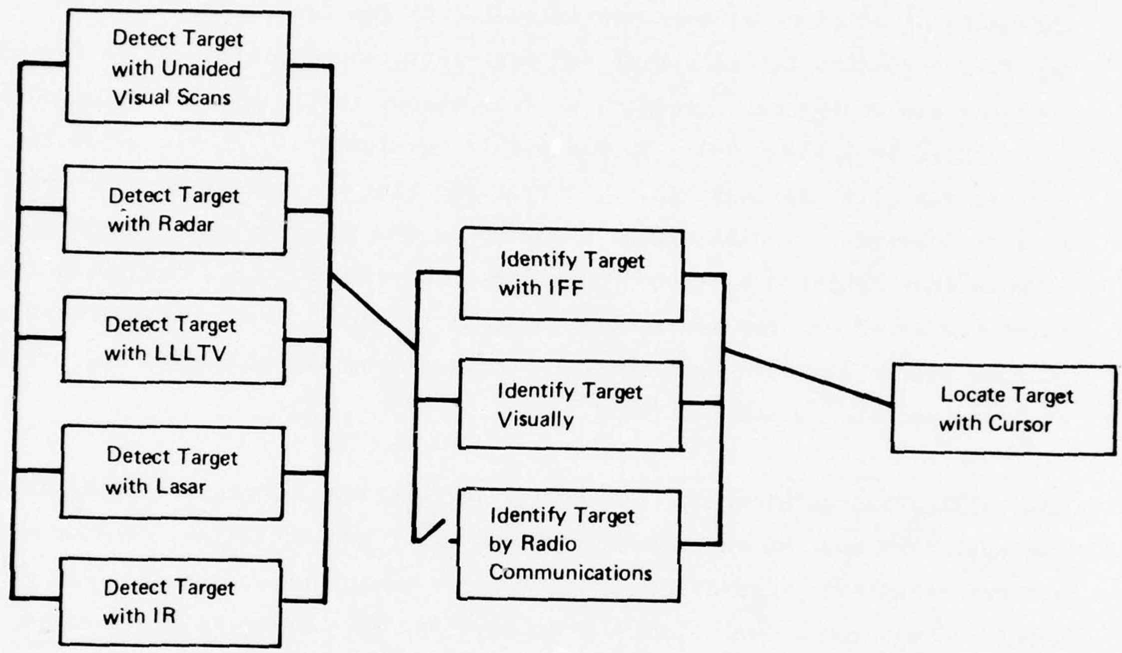

FIGURE 2.3-7: TARGET ACQUISITION MISSION OBJECTIVE

TABLE 2.3-4

EXAMPLES OF SUBSYSTEM ALLOCATIONS

Subsystem allocations to a task:

1. One crew member only.
2. One equipment type only.
3. Two crew members - parallel redundant.
4. Two crew members - sequential redundant.
5. Two equipments of same type in parallel.
6. Two equipments of different type in parallel.
7. One crew member and one equipment in parallel.
8. Two crew members and one equipment in parallel.
9. Two crew members in parallel with a third crew member as back-up.

2.3.4.1 (Continued)

Referring again to Figure 2.3-6, the next Function Allocation Model input item is task performance data. These data are used to compute mission success probabilities for the different allocation versions as is explained later in this section. Task data included under this category are:

1. Operator reliability as a function of task execution time.
2. Nominal task execution time.
3. Equipment reliability.
4. Task load ratings.
5. Task priority.
6. Task interruptability classification.
7. Task symbol.
8. Task classification.
9. Action mode.

Parameters 1-4 are used in the Mission Evaluator and parameters 5-9 are used solely by the Procedure Generator, which is discussed in the following text.

The output of the Mission Evaluator section of the Function Allocation Model is a table of mission objective success probabilities (Po) for each allocation version and each different mission objective specified.

PROCEDURE GENERATOR

The purpose of the Procedures Generator is to apply a list of all mission tasks against a specific scenario and ask the question "who is doing what, and when". Activity sequencing is determined by the Procedure Generator which observes rules and constraints prescribed by the HFE user. These rules and constraints include:

1. Prerequisite tasks
2. Mandatory procedures
3. Required simultaneity and task overlap exclusions
4. Earliest and latest task start times
5. Interruptability constraints
6. Maximum task loads per operator

2.3.4.1 (Continued)

The Procedures Generator combines data with other Function Allocation Model inputs, such as candidate functions allocations, task execution times, and task priorities to produce a task sequence for each operator in a crew-station. Both tabular and statistical outputs are produced. Tabular outputs are sufficient to construct Operational Sequence Diagrams (these diagrams are not a current CAFES capability). Statistical outputs covering task loading variables (Table 2.3-5) can include such information as percent of time each crew member is busy, or percent of time only one task is being executed by the crew.

All of these output data assist in the detailed evaluation of allocation versions, and they provide both quantitative and qualitative comparisons. For example, as function allocations are varied, the degree of operator interaction is affected (reflected in Operational Sequence Diagram data) as is the number of tasks that can be accomplished in a given time interval (statistical data). The Procedure Generator complements the Mission Evaluator because it provides further evidence to support a selection of function allocation versions for more detailed evaluation (e.g., by the Workload Assessment Model, the Computer Aided Design of Crewstation Model, etc.).

FUNCTION ALLOCATION MODEL OUTPUTS

Overall FAM operations and outputs are summarized in Figure 2.3-8 and 2.3-9. The two FAM submodels can produce the following outputs, according to specific constraints (e.g., time) input by the HFE user:

Mission Evaluator Highlights

- Mission objective(s) reliability estimates
- Overall mission reliability estimates
- Perceived task load
- Integrated Task reliabilities

Procedures Generator Highlights

- Percent of tasks interrupted and completed
- Percent of tasks interrupted and not completed
- Percent of tasks not started

TABLE 2.3-5 STATISTICAL OUTPUT FROM PROCEDURE GENERATOR

1. List of scheduled tasks that were not started at any time.
2. List of scheduled tasks that were started but not completed.
3. List of scheduled tasks that were interrupted and not completed.
4. List of scheduled tasks that were started late.
5. List of scheduled tasks that were interrupted and completed.
6. Percentages of total tasks in categories (a) through (e).
7. Percent of time only one task was being done.
8. Percent of time two tasks were being done.
9. Percent of time three or more tasks were being done.
10. Percent of time each operator is busy.

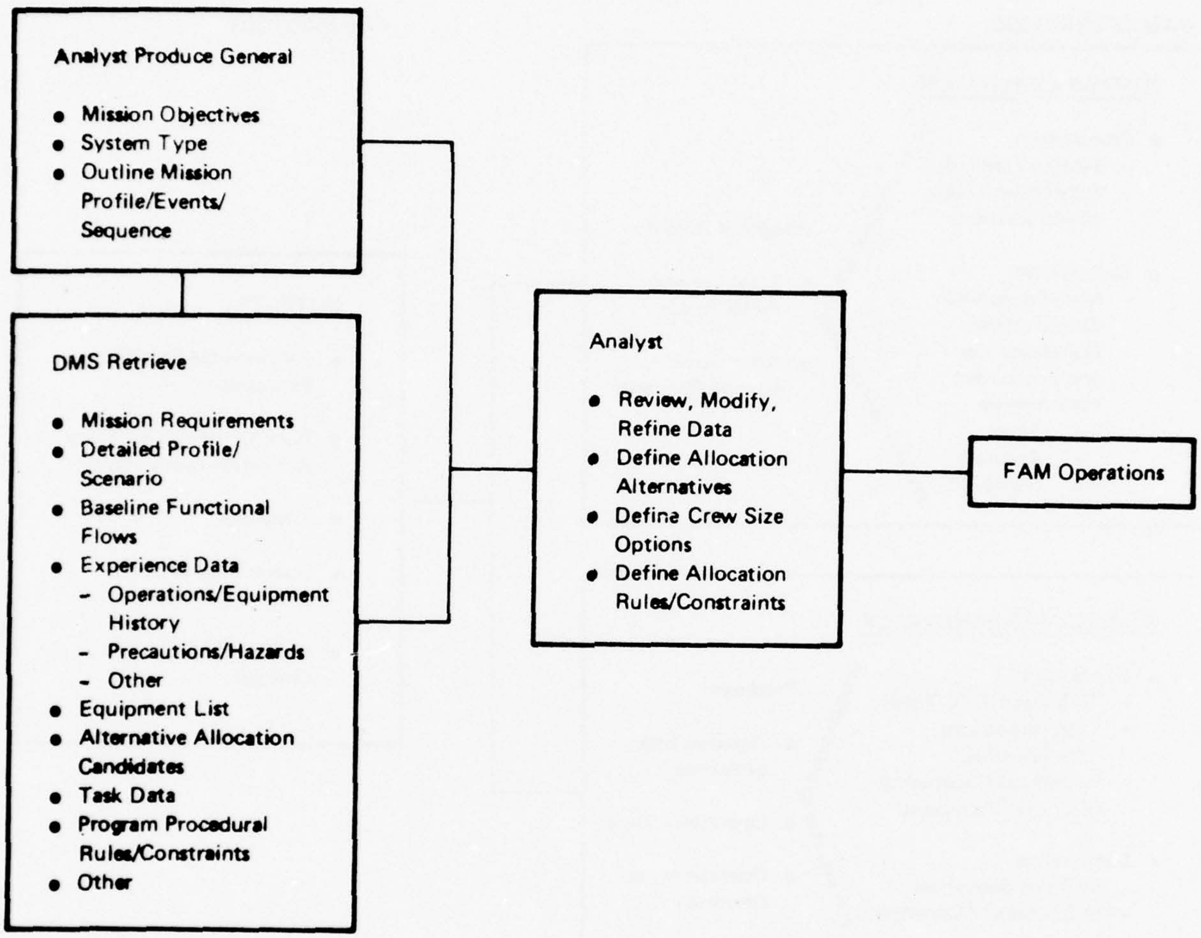

FIGURE 2.3-8: FAM MODEL DESCRIPTION-INPUT REQUIREMENTS

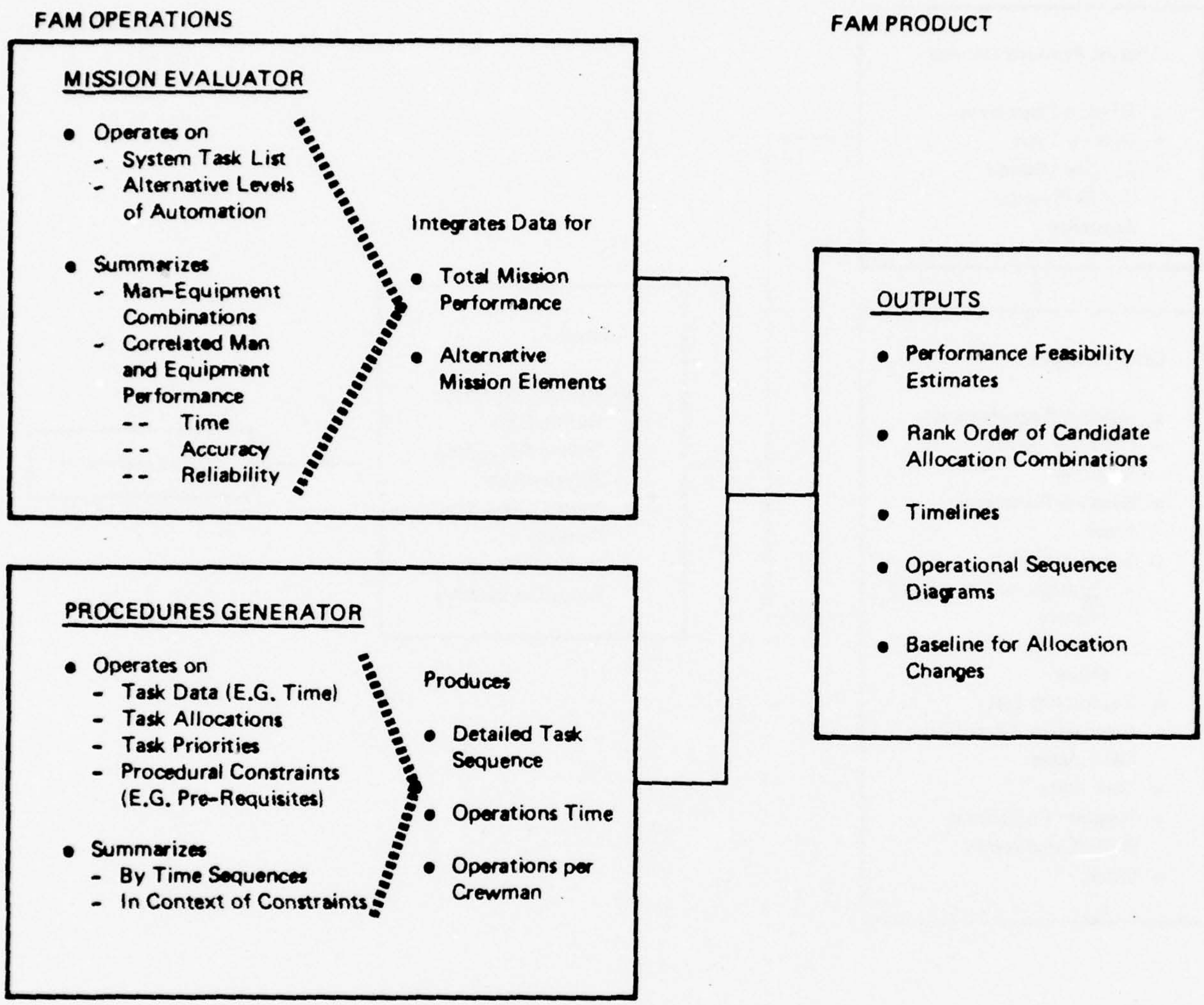

FIGURE 2.3-9: FAM MODEL DESCRIPTION-OPERATIONS AND OUTPUTS

2.3.4.1 (Continued)

Percent of tasks started but not completed

Percent of tasks started late

Percent of time operator busy

Tasks interrupted and completed

Tasks not started

Task simultaneity status

Tasks started late

Additionally, the FAM can output a detailed task timeline (much as is illustrated in Figure 2.3-10) as an input for the Workload Assessment Model.

2.3.4.2 Function Allocation Model Requirements Specification

The overall objective of the Function Allocation Model (FAM) is to assist the human factors engineer in identifying function allocations which are promising candidates for detailed evaluation (e.g., workload analysis, crew station design). Achievement of this objective implies compliance with a number of general and specific design requirements. The general FAM design requirements specification included:

- The FAM shall produce data to assist selection of function allocation candidates but leave final selection to professional judgment of the human factors engineer.
- The FAM shall provide quantitative comparisons of allocation alternatives on the basis of explicit criteria and provide traceability of all assumptions.
- The input and output formats for the FAM shall be designed for ease of use and interpretation by human factors engineers.
- The FAM shall be consistent with CAFES objectives and shall be designed for efficient interface with all other CAFES submodels.
- The FAM shall provide flexibility and options for by-passing detailed or complex portions of the model when such details are not required or are not warranted for a given analysis. This flexibility shall include the specification of model input data.
- The FAM shall be constructed on a modular basis for efficient model update or future modification, and also to facilitate operational flexibility.

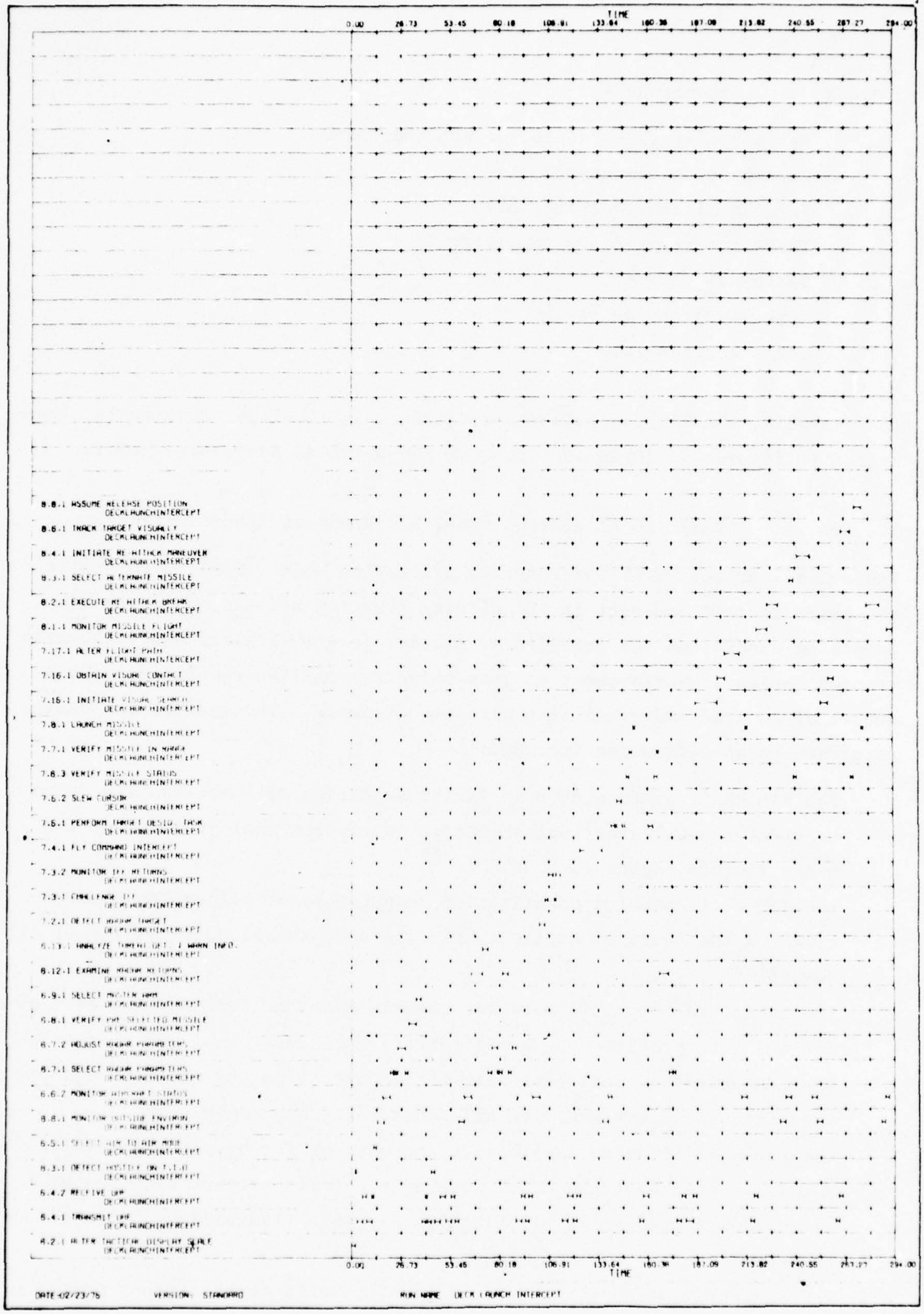

FIGURE 2.3-10: DETAILED TASK TIMELINE

2.3.4.2 (Continued)

- o The detailed structure of the FAM shall be designed for growth potential to accommodate new types of data and parametric relationships as they become available.

Detail design requirements specifications included:

- o The FAM shall provide means for identifying functions or tasks and how each is allocated to man and/or machine. Tasks shall be identifiable by name, symbol, and number (e.g., decimal number indenture according to the task's position in a functional flow block diagram). Allocations for each task shall be to one or more operators (20 maximum), to combination of man and machine, or to machines only. When allocations are to more than one operator/machine, the type of redundancy shall be defined, i.e., parallel or sequential redundancy. Combinations of redundancy types are also allowed. For example: two operators in parallel with a machine back-up (sequentially redundant).
- o Provision shall be made to specify up to 20 different allocation versions, where each version is a complete list of all mission tasks (together with how each task is allocated). The FAM shall be capable of fully specifying all allocation versions from a user prepared input of one complete version (standard version) and a statement of exceptions to the standard for each additional version.
- o The FAM shall provide for retrieval and display of allocation versions and for easy revision of allocation versions.
- o The FAM shall determine how different allocation versions affect mission success by computing probabilities of mission success for each allocation version. Mission success estimates shall be dependent on task performance which, in turn, shall be dependent on how tasks are allocated to man and/or machines. Task performance data for operators and equipment shall be input to FAM and these data combined to compute mission success probabilities.
- o Operator task performance data shall be in terms of nominal error rate (or reliability), nominal task execution time, and a function describing how task reliability varies with task execution time. FAM shall accommodate and utilize task performance data which can vary with

2.3.4.2 (Continued)

operational situation (e.g., aircraft cruise, aerial combat, terrain following etc.).

- o FAM shall provide an option to either input the task reliability versus task time functions as a table of points (15 pairs maximum) or as segments of second-degree polynomials (10 segments maximum).
- o FAM results shall be sensitive to assumptions in the mission scenario. That is, mission success predictions shall depend on the sequence of mission tasks that reflect assumptions on the type and timing of mission events. This dependence on scenario can be implemented by allowing the task sequence to impact time available to perform the tasks, which in turn affects task performance characteristics (via task reliability-versus-task time stress functions).
- o Provisions shall be made for storage, retrieval and display of mission scenario data which consist of (a) list of mission event names, (b) event times, (c) mission task names, (d) time at which each task begins, (e) task performance time intervals and (f) operational situations under which each task is being performed (e.g., aircraft dive, evasive maneuver, etc.). Provision shall be made for easy modification of mission scenario data.
- o FAM shall make first order estimates of crew workload during a mission for use in scaling nominal task execution times in order to reflect variations within and between different mission scenarios. Derived workload parameters shall include task difficulty factors such as precision, concentration, criticality, mission priority, and task continuity. Numerical ratings shall be assigned to these factors and the values shall be dependent on operational situation. These workload estimates shall be used to modify task execution time, which then impacts task performance and therefore affects mission success estimates.
- o FAM shall assist in evaluation of allocation alternatives by developing operational procedures for specified task allocation versions. Procedure data generated by FAM shall be sufficient to construct Operational Sequence Diagrams (OSD's) by manual or computer methods. Outputs for the OSD data and symbology information shall be consistent with standard methods.

2.3.4.2 (Continued)

o Inputs for operational procedures that shall be generated by the FAM to be consistent with user defined rules and constraints such as task prerequisites, task simultaniety, priorities, earliest start times, latest start times. The FAM shall be designed for ease of input and modification of these procedural data.

2.3.4.3 Function Allocation Model Relationship to Baseline HFE Methodology

FAM use requires data described in the baseline methodology section from the scenario, functional flows and alternate equipment candidates, including machine reliability, task reliability and task time. It can accept and use this data at different levels of detail or indenture, depending on analyst preference and availability of associated time and reliability data. Most desirably, the vast majority of data would be in considerable detail, available in storage and retrievable for ready decisions and model operations.

FAM picks up where the baseline methodology leaves off, extending the process to provide comparative appraisals of alternative combinations of equipment. Many user options exist, with the simplest being based on a cumulation of task and equipment reliabilities to produce an overall reliability estimate for each combination. Other options include such variations as incorporation of the constraints; a time stress weighting factor; and reliability variations according to criticality or time stress. The extent to which detailed data requirements might be necessary to exercise the options is illustrated by the Table 2.3-6 Summary of FAM Inputs.

A considerable number of elements in the FAM operation could be better defined for the user by extending the baseline process described to a total mission, as described under DMS discussion. This extension should include application and evaluation of various FAM options. Much of the HFE effort for any new system could then be significantly reduced through maximum utilization of pre-existing groundrules data, ratings and application procedures.

TABLE 2.3-6: FAM INPUTS

(MISSION EVALUATOR)	(PROCEDURE GENERATOR)
Average task reliability	Action mode
Machine reliability	Earliest start time
Mission objective	Interruptability classification
Mission scenario	Latest start time
Mission start time	Nominal task execution time
Mission stop time	Number of task repetitions
Mission time interval size	Priority
Nominal task execution time	RNO-Function
Operator reliability	Rule constraints
Reliability data number	Scenario event
Reliability curve segment data	Situation
Reliability weighting coefficients	Task name
Scenario events	Task allocation version
Situation	Task classification
Slide steptime interval	Task event
Stress correction factor	Task ID number
Task name	Task load score
Task allocation version	Task symbol
Task event	Umbrella tasks
Task ID number	
Task load score	
Task start time	
Task time scaler	
Time compression factor	

2.3.4.3 (Continued)

Additionally, FAM refinements should be incorporated to enhance user interface operations, including input and output formatting and interpretation.

In addition to data described under DMS discussion, major data elements that could be stored for FAM use include:

- Task time
- Task reliability
- Machine reliability
- Task criticality ratings
- Mission stress adjustment data
- Task time compression data

2.3.5 Workload Assessment Model (WAM)

2.3.5.1 Workload Assessment Model Concept

Basic requirements for initiating workload appraisals are that functions be allocated, that candidate equipment concepts and task details be identified, and that detailed task timelines and time constraints be known. Information is summarized in a detail task timeline, which may be produced as a FAM output, or from detailed development of all necessary tasks to meet the objectives of a mission or a mission segment including a critical task series. Early evaluations may be desired to establish configuration design or preliminary design concepts prior to starting development of a crew station configuration. Iterative evaluations are desirable with the evolution of detailed hardware definition and development to confirm continued suitability of crew workload with progressive design decisions. Alternatively, the configuration may be fixed before it is determined to be desirable to evaluate workload conditions.

The task timeline chart is the basic tool for initiating workload analyses. It illustrates detailed task sequencing and timing for one or more operators as function of mission elapsed time. While the timeline may be produced by the FAM, they have been most typically produced manually to result in formats such as the one shown in Figure 2.3-10 or the two types shown in Figure 2.3-11.

On a manual basis, the HFE analyst can review the task - timeline charts, evaluate task elements for possible difficulties, and examine proximal and simultaneous tasks to identify high workload or potential overload periods. Accordingly, tasks or subsystems contributing to such loads are readily identifiable. Given mission time constraints, e.g., weapon delivery, he can readily determine whether it is feasible to complete all necessary tasks in time, and can determine such feasibility for both normal and degraded modes. Results of such analyses can then be used to modify one or more of the following:

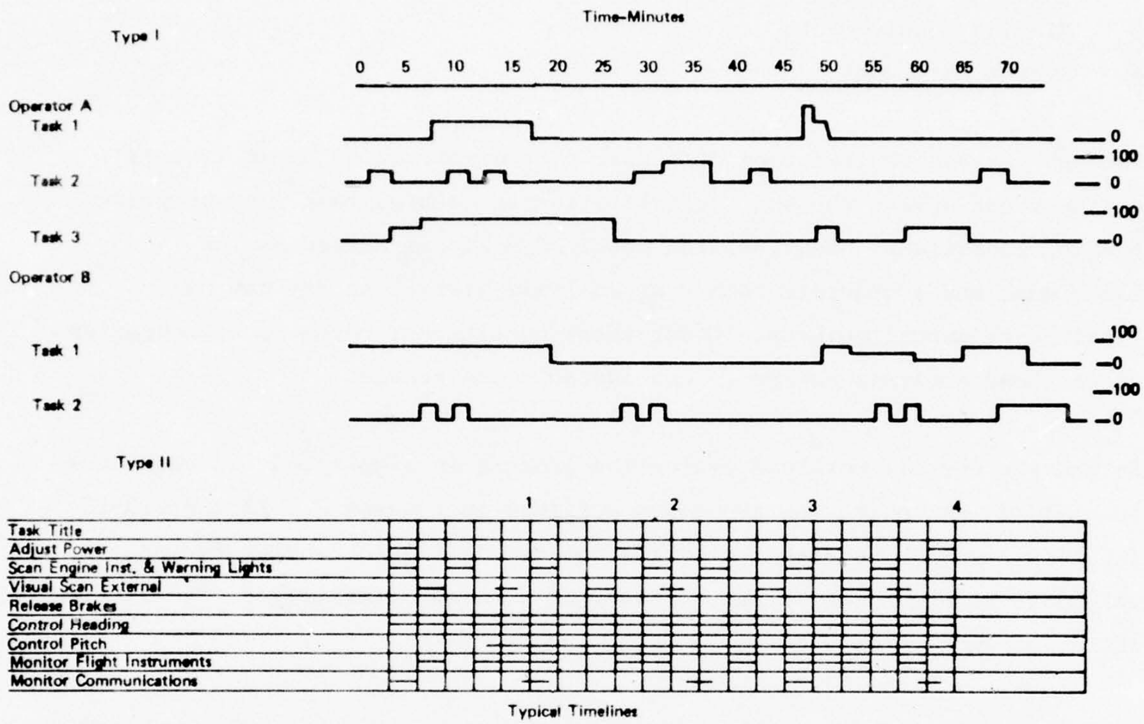

FIGURE 2.3-11; DETAILED TASK TIMELINE

2.3.5.1 (Continued)

- o Crew size
- o Man-machine task allocation
- o Intra-crew task allocation
- o Operational procedures (task sequence)
- o Mission requirements
- o System cost goal

Through successive iteration of possible trade-offs, the human factors engineer can derive the best overall solution to high task load or overloading conditions. However, the workload analysis method may be laborious, and a moderate number of analysis iterations may not be feasible by manual methods. Under these conditions, computer augmentation of workload analysis can be of considerable assistance.

In WAM the overall workload evaluation process is simplified and made less judgmental following the processes outlined in Figures 2.3-12 and 2.3-13. Input data can be constructed by the analyst in simple tabular format which can be organized by the computer in a format similarly to the listings of Tables 2.3-7 and 2.3-8.

WAM may be applied for single or multiple crewmen. However, the workload is analyzed independently for each crewman, and the tabular and graphical outputs will be specified by crewmen. Reports provide tabular and graphical workload data for each crewman and eight channels of activity (reflecting Crewman, External Vision, Internal Vision, Left Hand, Right Hand, Left Foot, Right Foot, Cognitive, Auditory and Verbal). Graphical reports currently available include:

1. Play back of the task timeline in the form of an I bar chart (an element that can also be produced by FAM for WAM input data).
2. Workload time history (by channel and averages)
3. Workload barchart (with and without one sigma deviations reflecting channel loading variations over the course of the mission).

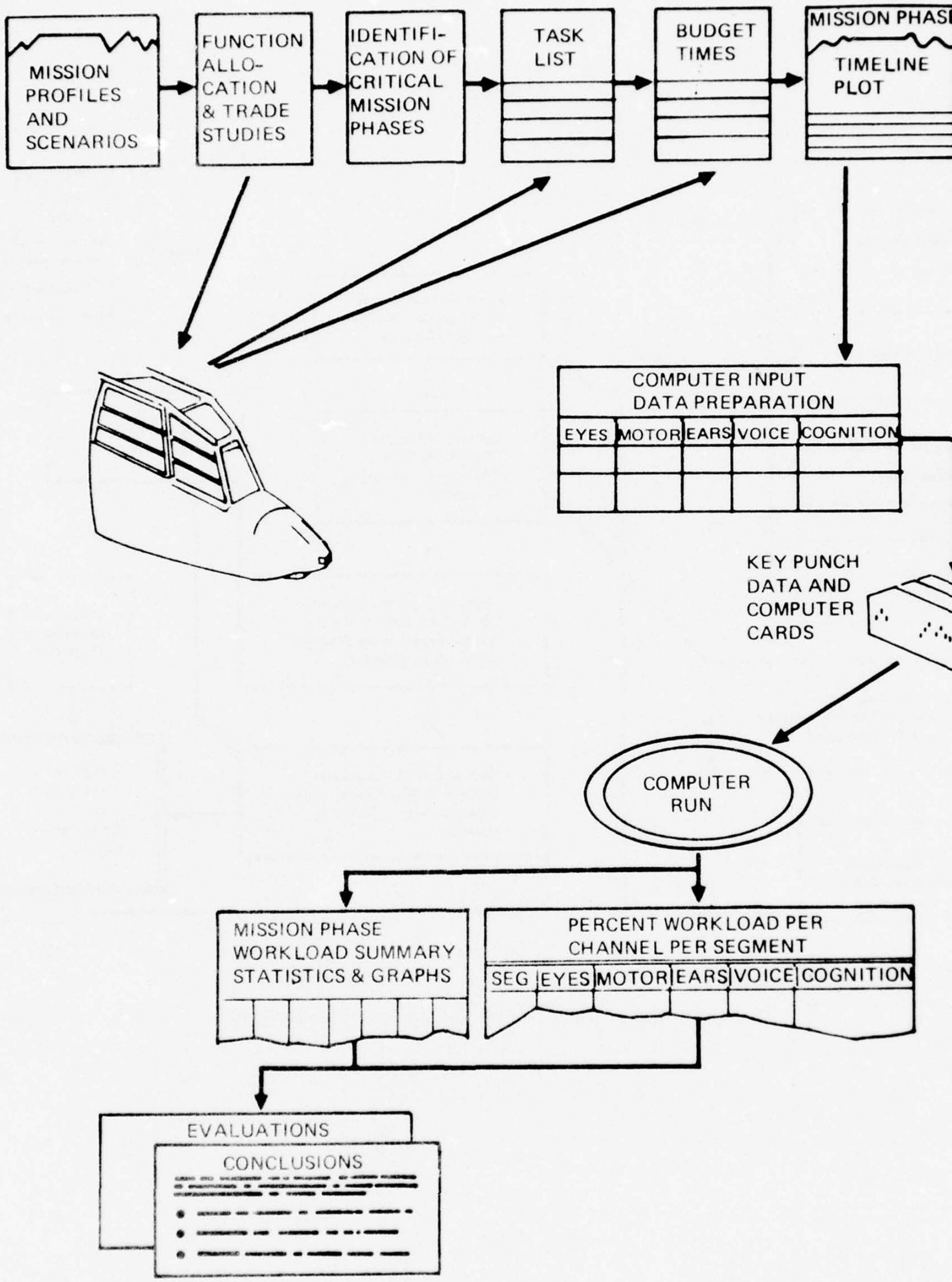

FIGURE 2.3-12: WORKLOAD MEASUREMENT PROCESS

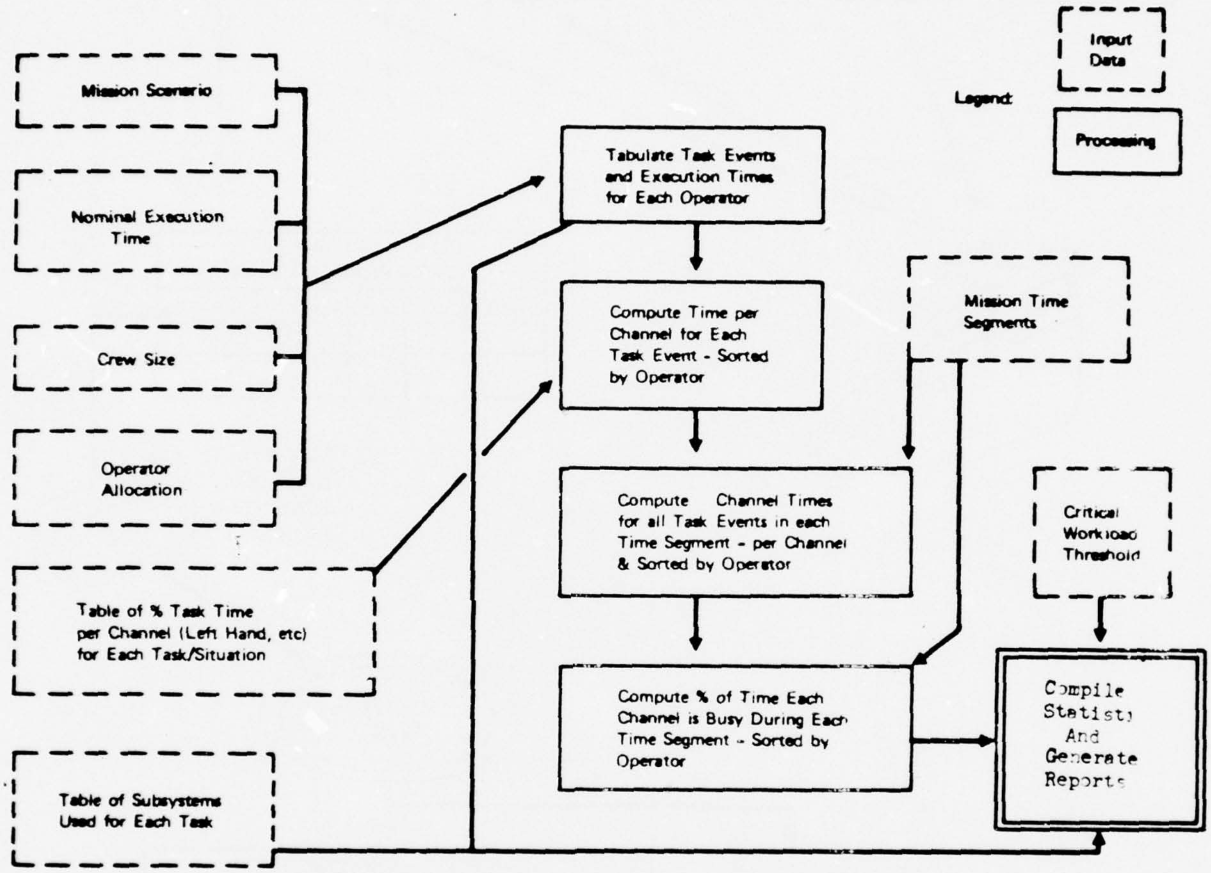

FIGURE 2.3-13: WAM DATA PROCESSING

COMPUTER AIDED FUNCTION-ALLOCATION EVALUATION SYSTEM

```
BEGIN CAFES= CREATE NEW DATA BANK/
     BEGIN DATA BANK ECITOR/ C1= PILOT/
     TASK= 5.1 MAINTAIN FLIGHT CONTROL/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=70. / IV=30. / LH=100./ RH=100./ LF=10. / RF=10. /
                    COG=10. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=0.  / IV=100./ LH=0.  / RH=0.  / LF=0.  / RF=0.  /
                    COG=30. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2.1 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=10. / IV=90. / LH=25. / RH=70. / LF=25. / RF=25. /
                    COG=30. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2.2 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=10. / IV=90. / LH=100./ RH=100./ LF=20. / RF=20. /
                    COG=40. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2.3 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=30. / IV=70. / LH=80. / RH=100./ LF=20. / RF= 20. /
                    COG=50. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK=5.2.4 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=20. / IV=80. / LH=100./ RH=100./ LF=10. / RF=10. /
                    COG=30. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2.5 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=60. / IV=40. / LH=100./ RH=100./ LF=80. / RF=80. /
                    COG=40. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2.6 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=10. / IV=90. / LH=60. / RH=70. / LF=20. / RF=20. /
                    COG=30. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2.7 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=40. / IV=60. / LH=80. / RH=100./ LF=50. / RF=50. /
                    COG=40. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.2.3 CHECK FLIGHT INSTRUMENTS/
          ALLOCATION LOGIC= C1/
          SITUATION= CLOSE AIR SUPPORT/
          CHANNEL= C1/ EV=30. / IV=70. / LH=60. / RH=60. / LF=10. / RF=10. /
                    COG=20. / AUD=0.  / VERB=0.  / END CHANNEL/
     TASK= 5.3 CHECK ENGINE INSTRUMENTS/
```

TABLE 2.3-8: WAM TASK INPUT

```
    ESTART=  8./ EDURATION= 3.0/
EVENT=   2/ ETASK= 5.2.1  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=  3./ EDURATION= 3.0/
EVENT=   3/ ETASK= 5.3.1  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=  6./ EDURATION= 2.0/
EVENT=   4/ ETASK= 5.4.1  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=  8./ EDURATION= 1.5/
EVENT=   5/ ETASK= 5.5    / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 10./ EDURATION= 2.0/
EVENT=   6/ ETASK= 8.2.1  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 17./ EDURATION= 1.5/
EVENT=   7/ ETASK= 8.2.1  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 19./ EDURATION= 1.5/
EVENT=   8/ ETASK= 8.2.3  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 21./ EDURATION= 2.5/
EVENT=   9/ ETASK= 8.2.4  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 25./ EDURATION= 6.0/
EVENT=  10/ ETASK= 8.2.5  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 32./ EDURATION=12.0/
EVENT=  11/ ETASK= 8.2.4  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 44./ EDURATION= 4.0/
EVENT=  12/ ETASK= 8.2.5  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 48./ EDURATION= 4.0/
EVENT=  13/ ETASK= 8.2.4  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 53./ EDURATION= 6.0/
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EVENT=  15/ ETASK= 8.2.6  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 63./ EDURATION=10.0/
EVENT=  16/ ETASK= 8.2.4  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 74./ EDURATION= 3.0/
EVENT=  17/ ETASK= 8.2.5  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 77./ EDURATION= 1.0/
EVENT=  18/ ETASK= 8.2.4  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 82./ EDURATION= 6.0/
EVENT=  19/ ETASK= 8.2.5  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 88./ EDURATION= 3.0/
EVENT=  20/ ETASK= 8.2.4  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 91./ EDURATION= 3.0/
EVENT=  21/ ETASK= 8.2.5  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART= 94./ EDURATION= 5.0/
EVENT=  22/ ETASK= 5.2    / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=100./ EDURATION= 3.0/
EVENT=  23/ ETASK= 5.4    / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=103./ EDURATION= 1.0/
EVENT=  24/ ETASK= 5.5    / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=104./ EDURATION= 1.5/
EVENT=  25/ ETASK= 8.4.1  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=106./ EDURATION= 2.0/
EVENT=  26/ ETASK= 8.2.3  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=108./ EDURATION= 2.5/
EVENT=  27/ ETASK= 8.2.3  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=111./ EDURATION= 1.5/
EVENT=  28/ ETASK= 8.2.3  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=113./ EDURATION= 1.5/
EVENT=  29/ ETASK= 8.5.4  / ESITUATION= CLOSE AIR SUPPORT/
    ESTART=115./ EDURATION= 4.0/
```

TABLE 2.3-7: WAM EVENT LIST

Timeline plots(Figure 2.3-10) can be produced by WAM to summarize tabular inputs. Plots are a chart of tasks on the ordinate and time along the abscissa. Task execution is depicted by a bar opposite the task and in the time frame performed.

The Workload Barchart and Barchart Plus One Sigma variation plot provides a graphical representation of the statistical analysis performed on channel activity. The bars represent average activity channel and collective averages of visual, motor, communication and overall activity. This presentation can be used for quick overviews of workload comparisons between crew members, between channels, between mission phases/situations, or between different candidates for function allocation, system design, and operating procedures.

The operator workload versus time is a graphical representation with lines connecting to workload level at a midpoint of its time segment. This graphical representation provides the instantaneous level up to a maximum of 160%. Individual channel activities (internal vision, external vision, left hand, etc.) are depicted, as well as group and total averages. The production of the graphical output provides a readily understandable means of identifying potential problem areas and the means to convey these concerns to parties concerned with the selection of the desired configuration and design.

Task shifting for less critical tasks is an HFE analyst option. Provisions are made in the Workload Assessment Model operations to automatically rearrange the times which specified tasks identified as not time critical may be executed. A "shifting" feature attempts to move the large time non-critical activities out of an overloaded time segment by shifting to later time segments or earlier time segments. The task or tasks will be shifted if overloading of other time segments will occur. The amount of departure from the nominal start time is within preassigned limits in which shifting can occur. No shift occurs when the realignment of tasks forces a new time segment into an overload situation. Those segments

2.3.5.1 (Continued)

that can be shifted successfully are identified by an asterisk (*) along side to time segment containing the shifted task. The operator can specify whether shifting will occur only to an earlier time, by using a minus value, or to be shifted to a later period, with a positive step value, or to either. In the event a shifted task is unacceptable to the analyst, it is only necessary to rerun the Workload Assessment Model with controls which preclude the selection of an undesirable time period for a specified task.

WAM outputs include:

1. Crew workload level versus mission time
2. Task activity
3. Subsystem activity
4. Mission scenario or segment summaries

2.3.5.2 Workload Assessment Model Requirements Specification

The overall objective of the WAM is to assist the human factors engineer in analyzing operator workload imposed on each crew member assigned to operate a system. This analysis, as pointed out earlier, can entail a number of subtle factors. It is a general requirement on WAM to facilitate the analysis of any or all these factors - at the option of the WAM user. Additional general requirements are listed below. These are followed by a list of specific design requirements.

- The Workload Assessment Model shall compute operator workload data according to criteria established by the model user and final evaluation of alternative system/operational concepts shall be made by the human factors engineer.
- The input and output formats for the Workload Assessment Model shall be designed for ease of use and interpretation by human factors engineers.
- The Workload Assessment Model shall be consistent with CAFES objectives and shall be designed for efficient interface with all other CAFES submodels.

2.3.5.2 (Continued)

- o The Workload Assessment Model shall provide flexibility and options for by-passing detailed or complex portions of the model when such details are not required or are not warranted for a given analysis. This flexibility shall include the specification of model input data.
- o The Workload Assessment Model shall be constructed on a modular basis for efficient model update or future modification and also to facilitate operational flexibility.
- o The detailed structure of the Workload Assessment Model shall be designed for growth potential to accommodate new types of data and parameter relationships as they become available.

Specific requirements on Workload Assessment Model design, in addition to these general requirements, are listed below:

- o The Workload Assessment Model shall provide means for statistical evaluation by operator channel (eyes, hands, feet, etc.).
- o The Workload Assessment Model shall compute averages and standard deviations for operator workload variations during a specific mission phase. Mission phases are segmented into equal time increments and the workload per channel in each time segment is defined for each crew member in terms of percent time the channel is active.
- o Channel workload inputs shall be computed automatically, using data parameters common to the Function Allocation Model whenever possible, i.e.: mission scenario, task execution times, mission time segments, crew size, and operator allocation (Figure A-20).
- o The Workload Assessment Model shall provide sensitivity to operational situations and automatically identify and tabulate critical workload periods when workload exceeds "critical workload threshold."
- o The Workload Assessment Model shall tabulate and plot (in histogram form) the following information for each critical workload period:
  - Which subsystems are utilized during each critical period. (Plot not required.)
  - Amount of time each subsystem is used during each critical period.

2.3.5.2 (Continued)

- Which tasks are being executed during each critical period. (Plot not required.)
- Percent of time during each critical period that each task is active.
- Data items, above, for the sum of all critical item periods.

o Channel breakdown in Workload Assessment Model shall include:
- External vision
- Internal vision
- Right hand
- Left hand
- Right foot
- Left foot
- Cognition
- Auditory
- Verbal

Summary data shall be computed for the following categories:
- Total vision
- Total motor
- Total communications

2.3.5.3 WAM Application and Data

Data used for examples and illustrations in subsequent discussion reflects the results from application of WAM during this study for the mission scenario described earlier in this report, manual functions-allocations assumptions, and manual development of task time-sequencing data. The model was applied in preliminary evaluation of early concepts.

The procedure for preparing data for Workload Assessment Model is as follows (Figure 4-2):

1. Utilizing performance manuals and standard operating procedures, a mission profile and scenario is prepared in which time, event, distance, altitude and speed are sequenced over the entire mission.

2.3.5.3 (Continued)

2. A mission phase chart is constructed, dividing the mission into phases in which times for each phase are assigned on the basis of operational experience and estimates from simulation studies.
3. Task definition and time allocation involves the assignment of task names to the procedures or events identified in the previous step, as well as to the elements of task analyses where available.
4. On the basis of the task definition/time data, a mission phase time-line analysis is prepared, dividing the mission phase into six second segments (or any other time period desired) and showing which tasks are employed in each segment.
5. Next is the determination of channel utilization times over the mission. A typical channel time budget sheet lists the modality channels (visual, motor/manual, cognitive, auditory, verbal), type of task, and the number of the designated task. The numbers contained in the modality columns represent "channel utilization" times, or the time in seconds that a particular channel is used during one mission time segment. This concludes the manual data preparation and channel utilization data are then keypunched for execution of the Workload Assessment Model.

Application of WAM is based on comparing time required to perform a task sequence with time available for performance to establish a ratio reflecting excess or negative time to perform. This comparison is made for all crew interface channels, i.e., eyes, right hand, left hand, right foot, left foot, auditory, verbal and cognition. When WAM receives the channel workload data for each time segment, it proceeds to compute the channel utilization in terms of percent rather than in time units (sec.). For instance, if each segment is 6 seconds, the formula is:

$$\text{percent utilization} = \frac{\text{channel utilization (seconds)}}{\text{6 seconds}} \times 100$$

Next, WAM computes averages, standard deviations, and variances for channel workloads as they vary over all the time segments in each defined

mission phase. For example, in a mission phase such as target acquisition lasting, say, five minutes, the number of segments = $\frac{5 \times 60}{6}$ = 50 segments and therefore 50 values of percent workload would be input to the computation of averages, etc. This computation is repeated for each channel, each operator, and each defined mission phase.

Output in the WAM program consists of both tabular and plotted statistical summaries. For each crewman, a table is produced showing workload per channel per segment. Workload figures are expressed as percentages, figures over 100% indicating the existence of an overload condition, while figures over 75% are taken as potentially degrading to performance.

Computer plots utilizing the bargraph and histogram techniques are available to the human factors engineer to compare workload per channel between types configurations and function allocations. Histogram plots depict the percentage of workloading over the various mission phases. Examples of these plots follow, and are also in the User's Guides (References 24, 26, and 28).

As indicated earlier WAM outputs include :

1. Crew workload versus mission time
2. Task activity
3. Subsystem activity
4. Mission scenario or segment summaries

The first two reports provide workload data for each crewman and all eight channels of activity. Representative tabular, barchart and graphic outputs are shown in Figures 2.3-14 through 2.3-32. These outputs permit workload evaluation by the analyst for such questions as mission phase loading, relative channel loading and potential overloads. Workload time history graphs (Figures 2.3-18 through 2.3-30) identify specific mission time frames where actual or potential overloads exist. Undesirable loading

CREWMAN WORKLOAD REPORT - CREWMAN 1 PILOT

VERSION STANDARD

TIME INTERVAL START	END	EXT VISION	INT VISION	RGT HAND	LEFT HAND	RGT FOOT	LEFT FOOT	COGNITION	AUDIO	VERBAL	TOTAL VISION	TOTAL MOTOR	TOTAL COMM	AVERAGE
0/	6	42.5	57.5	70.0	25.0	25.0	25.0	20.0	.0	.0	100.0	36.3	.0	37.9
6/	12	5.8	85.8	40.8	14.6	14.6	14.6	20.0	.0	.0	91.7	21.1	.0	28.2
12/	18	.0	16.7	.0	.0	.0	.0	4.2	.0	.0	16.7	.0	.0	3.0
18/	24	.0	75.0	41.7	.0	.0	.0	12.5	.0	.0	75.0	10.4	.0	18.5
24/	30	.0	.0	.0	83.3	.0	.0	8.3	.0	83.3	.0	20.8	41.7	25.0
30/	36	.0	.0	.0	16.7	.0	.0	41.7	66.7	16.7	.0	4.2	41.7	20.2
36/	42	.0	.0	.0	.0	.0	.0	60.0	100.0	.0	.0	.0	50.0	22.9
42/	48	.0	.0	.0	66.7	.0	.0	26.7	33.3	66.7	.0	16.7	50.0	27.6
48/	54	.0	.0	.0	16.7	.0	.0	41.7	66.7	16.7	.0	4.2	41.7	20.2
54/	60	.0	.0	.0	83.3	.0	.0	18.3	16.7	83.3	.0	20.8	50.0	28.8
60/	66	50.0	.0	10.0	.0	5.0	5.0	25.0	16.7	.0	50.0	5.0	8.3	16.0
66/	72	100.0	.0	20.0	.0	10.0	10.0	30.0	.0	.0	100.0	10.0	.0	24.3
72/	78	16.7	.0	3.3	50.0	1.7	1.7	20.0	16.7	50.0	16.7	14.2	33.3	22.9
78/	84	.0	.0	.0	33.3	.0	.0	3.3	.0	33.3	.0	8.3	16.7	10.0
84/	90	.0	.0	.0	66.7	.0	.0	26.7	33.3	66.7	.0	16.7	50.0	27.6
90/	96	.0	.0	.0	50.0	.0	.0	35.0	50.0	50.0	.0	12.5	50.0	26.4
96/	102	.0	33.3	.0	.0	.0	.0	40.0	50.0	.0	33.3	.0	25.0	17.6
102/	108	.0	91.7	.0	25.0	.0	.0	21.7	.0	.0	91.7	6.3	.0	19.8
108/	114	.0	83.3	83.3	.0	.0	.0	8.3	.0	.0	83.3	20.8	.0	25.0
114/	120	.0	91.7	91.7	.0	.0	.0	84.2	.0	.0	91.7	22.9	.0	38.2
120/	126	.0	50.0	50.0	.0	.0	.0	50.0	.0	.0	50.0	12.5	.0	21.4
126/	132	.0	100.0	66.7	.0	.0	.0	38.3	.0	.0	100.0	16.7	.0	29.3
132/	138	.0	100.0	.0	.0	.0	.0	18.3	.0	.0	100.0	.0	.0	16.9
138/	144	.0	75.0	58.3	.0	.0	.0	9.2	.0	.0	75.0	14.6	.0	20.4
144/	150	.0	75.0	75.0	[illegible]	.0	.0	67.5	.0	.0	75.0	18.7	.0	31.1
150/	156	5.0	70.0	45.0	.0	.0	.0	52.5	.0	.0	75.0	11.3	.0	24.6
156/	162	7.5	67.5	13.3	41.7	.0	.0	54.2	.0	.0	75.0	13.7	.0	26.3
162/	168	.0	91.7	.0	91.7	.0	.0	27.5	.0	.0	91.7	22.9	.0	30.1
168/	174	.0	100.0	.0	83.3	.0	.0	41.7	.0	.0	100.0	20.8	.0	32.1
174/	180	.0	91.7	16.7	25.0	.0	.0	59.2	.0	.0	91.7	10.4	.0	27.5
180/	186	41.7	58.3	100.0	83.3	54.2	54.2	60.0	.0	.0	100.0	72.9	.0	64.5
186/	192	16.7	75.0	33.3	33.3	20.8	20.8	35.0	.0	.0	91.7	27.1	.0	33.6
192/	198	.0	.0	.0	50.0	.0	.0	25.0	33.3	50.0	.0	12.5	41.7	22.6
198/	204	13.3	53.3	13.3	.0	.0	.0	66.7	.0	.0	66.7	3.3	.0	21.0
204/	210	20.0	80.0	20.0	.0	.0	.0	100.0	.0	.0	100.0	5.0	.0	31.4
210/	216	6.7	93.3	73.3	.0	.0	.0	70.0	.0	.0	100.0	18.3	.0	34.8
216/	222	6.7	68.3	75.0	33.3	6.7	6.7	25.0	.0	.0	75.0	30.4	.0	31.0
222/	228	20.0	80.0	100.0	100.0	20.0	20.0	20.0	.0	.0	100.0	60.0	.0	51.4
228/	234	10.0	90.0	100.0	100.0	20.0	20.0	30.0	.0	.0	100.0	60.0	.0	52.9
234/	240	6.7	93.3	93.3	73.3	20.0	20.0	66.7	.0	.0	100.0	51.7	.0	53.3
240/	246	46.7	86.7	120.0	100.0	23.3	23.3	56.7	.0	.0	133.3	66.7	.0	65.2
246/	252	60.0	23.3	33.3	13.3	33.3	33.3	70.0	.0	.0	83.3	28.3	.0	38.1
252/	258	90.0	10.0	66.7	46.7	36.7	36.7	73.3	.0	.0	100.0	46.7	.0	51.4
258/	264	56.7	43.3	100.0	100.0	10.0	10.0	26.7	.0	.0	100.0	55.0	.0	49.5

FIGURE 2.3-14: CREWMAN WORKLOAD REPORT

CREWMAN WORKLOADING SUMMARY - CREWMAN 1 PILOT
AVERAGE AND STANDARD DEVIATION PER UNIT TIME

VERSION STANDARD

CHANNEL	SUM X	SUM X SQUARED	AVERAGE LOAD	VARIANCE	STANDARD DEVIATION
1	1953.33	102741.7	18.60	638.495	25.260
2	5180.00	305533.3	49.33	1249.872	35.354
3	4454.17	334434.0	42.42	1398.899	37.402
4	3698.75	239771.7	35.23	1052.681	32.445
5	1156.25	44208.5	11.01	302.654	17.397
6	1156.25	44208.5	11.01	302.654	17.397
7	4138.75	215695.3	39.42	505.381	22.481
8	1100.00	56250.0	10.48	430.060	20.738
9	1016.67	53611.1	9.68	420.838	20.514
11	7133.33	641666.7	67.94	1510.124	38.860
12	2616.35	109731.2	24.92	428.248	20.694
13	1058.33	42465.3	10.08	305.750	17.486
14	3407.74	131565.7	32.45	201.623	14.199

FIGURE 2.3-15: CREWMAN WORKLOAD SUMMARY

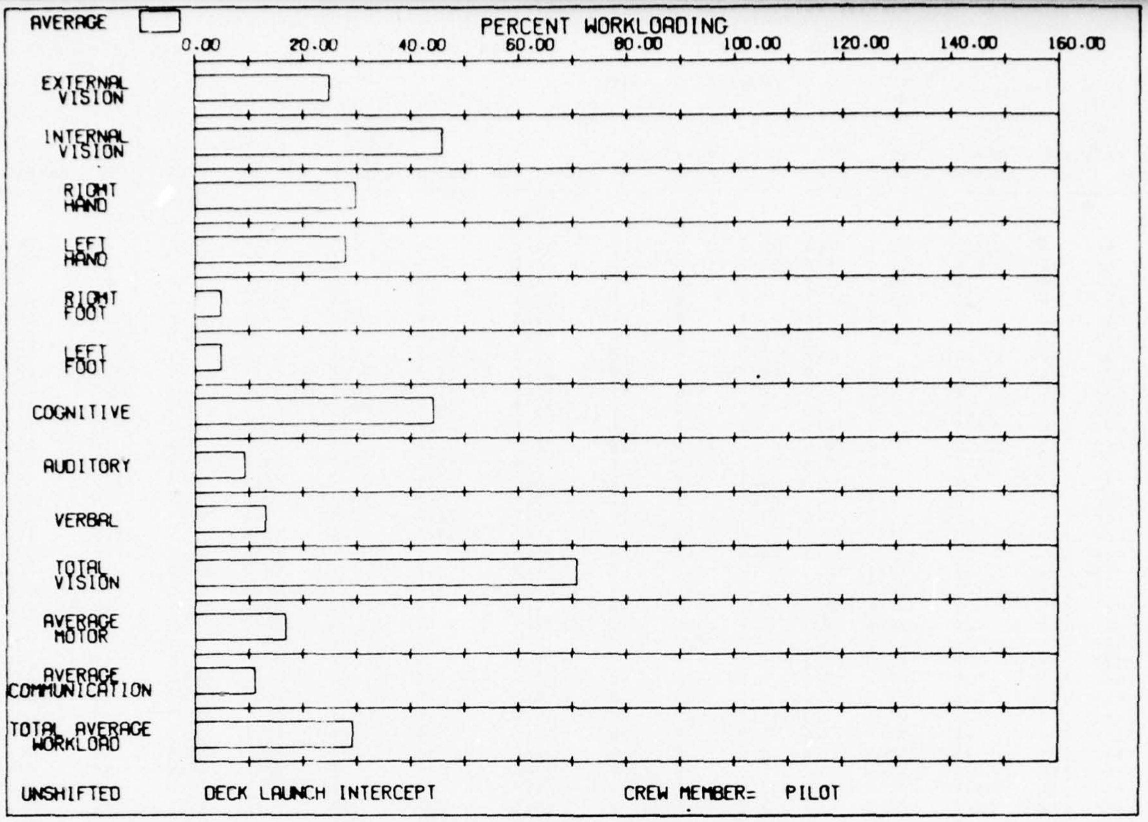

FIGURE 2.3-16: WORKLOAD BARCHART SUMMARY

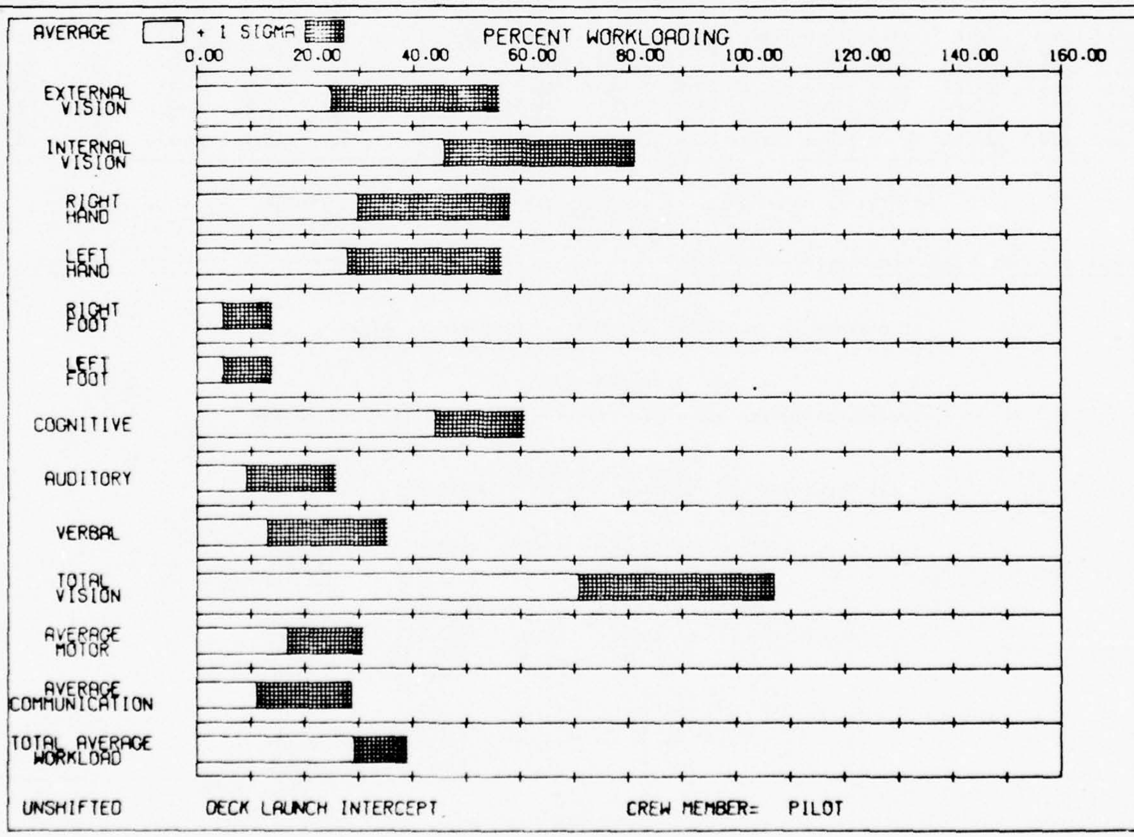

FIGURE 2.3-17: WORKLOAD BARCHART SUMMARY PLUS ONE SIGMA

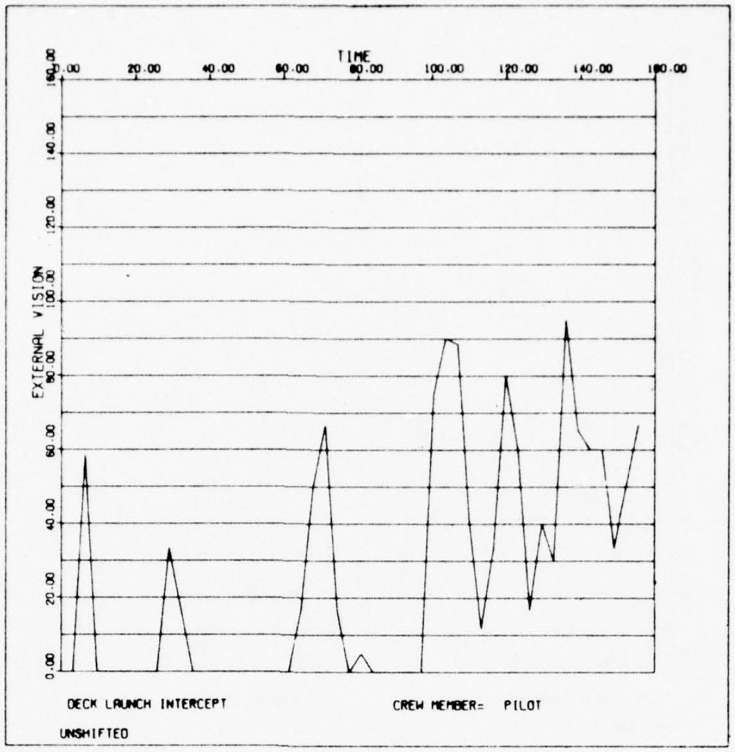

FIGURE 2.3-18: EXTERNAL VISION WORKLOAD TIME HISTORY

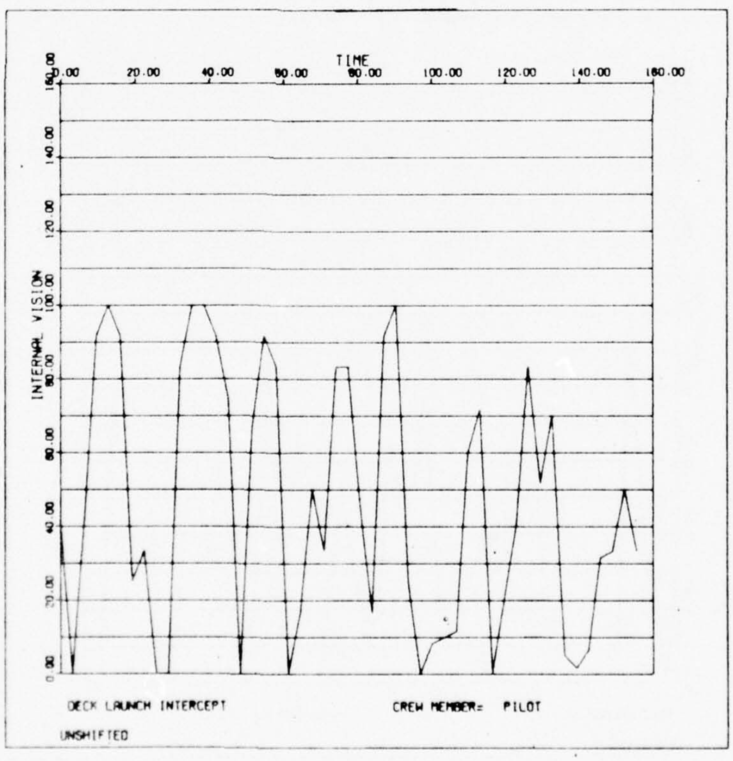

FIGURE 2.3-19: INTERNAL VISION WORKLOAD TIME HISTORY

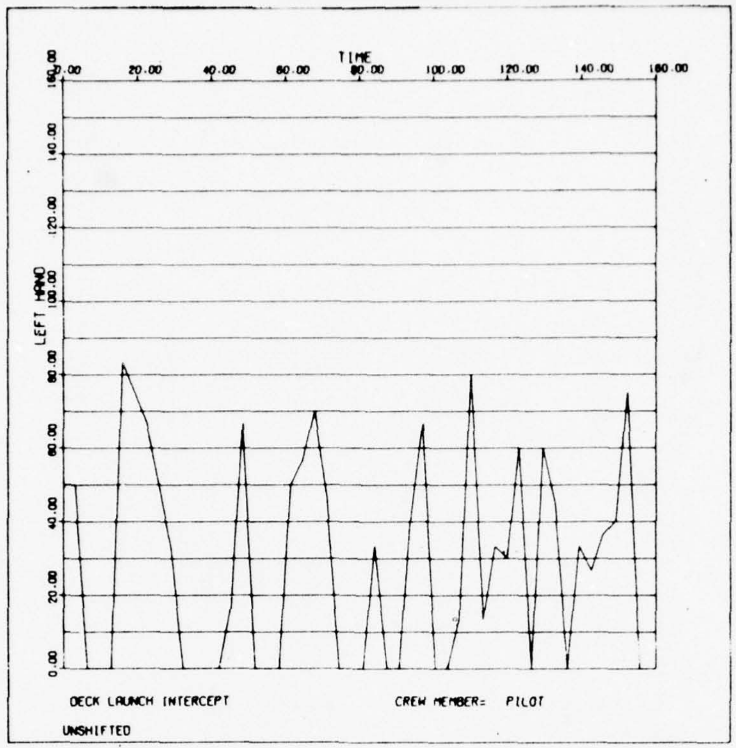

FIGURE 2.3-20: LEFT HAND WORKLOAD TIME HISTORY

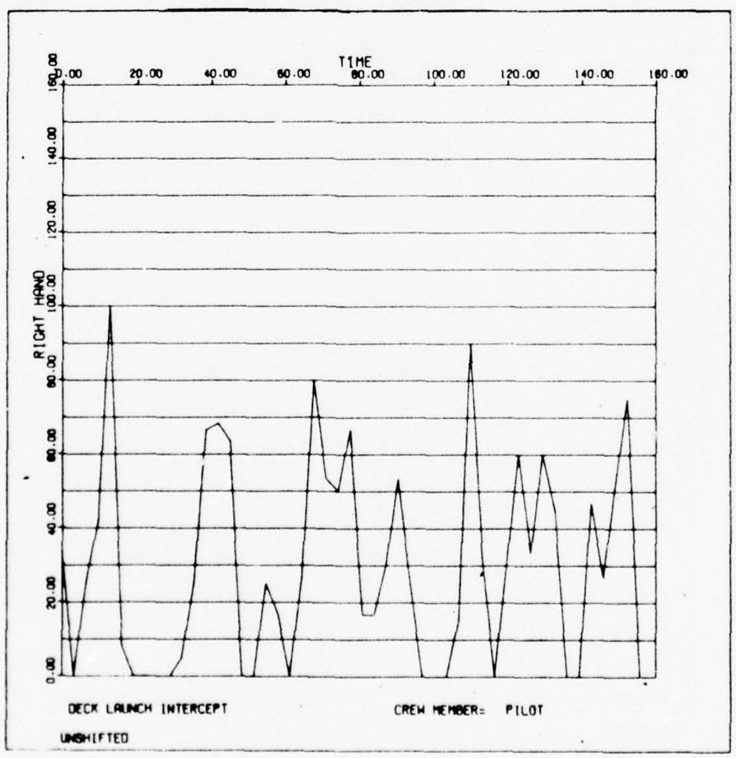

FIGURE 2.3-21: RIGHT HAND WORKLOAD TIME HISTORY

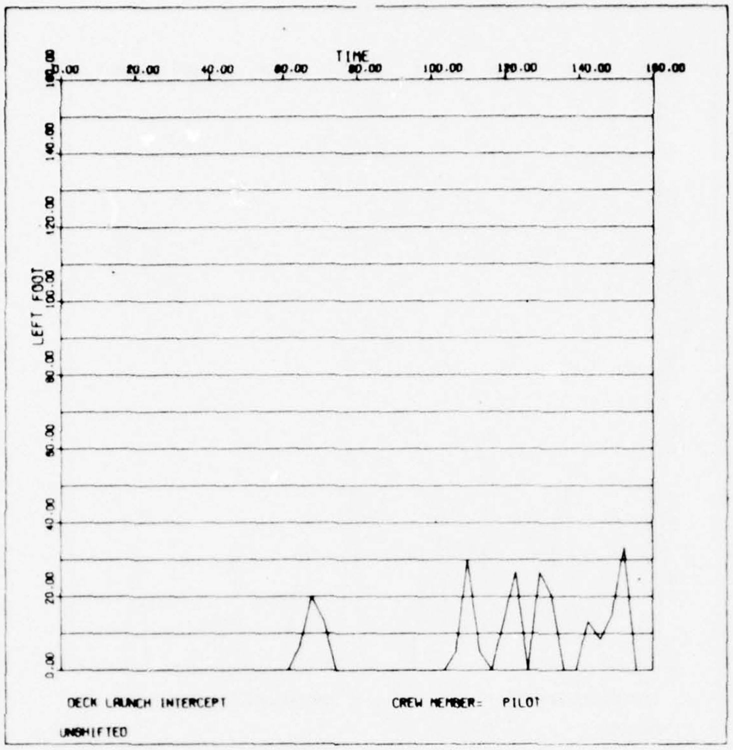

FIGURE 2.3-22: LEFT FOOT WORKLOAD TIME HISTORY

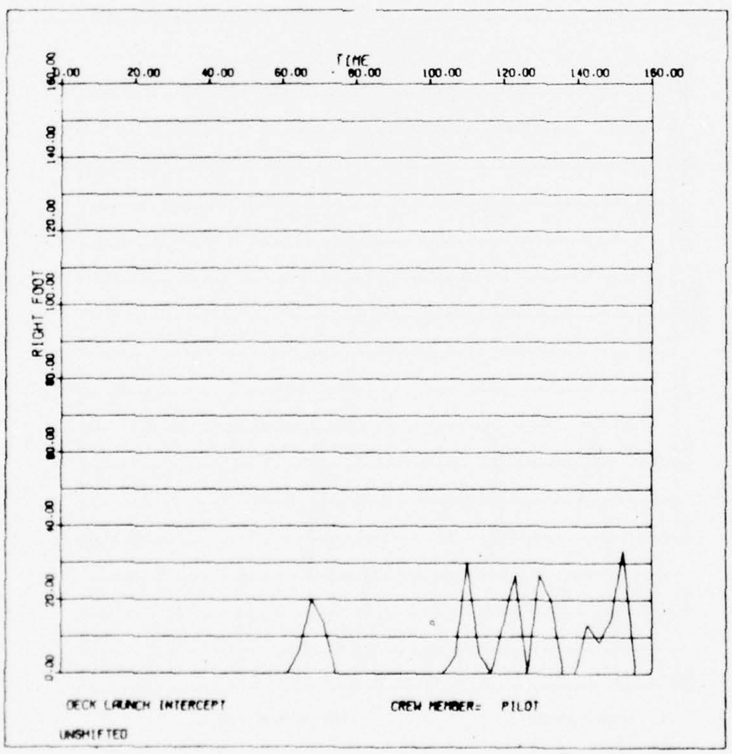

FIGURE 2.3-23: RIGHT FOOT WORKLOAD TIME HISTORY

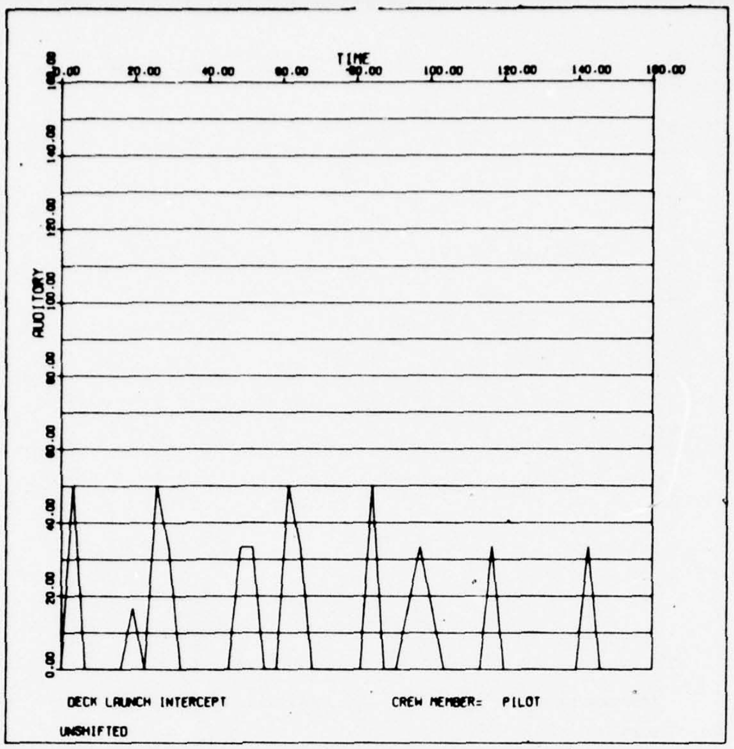

FIGURE 2.3-24: AUDITORY WORKLOAD TIME HISTORY

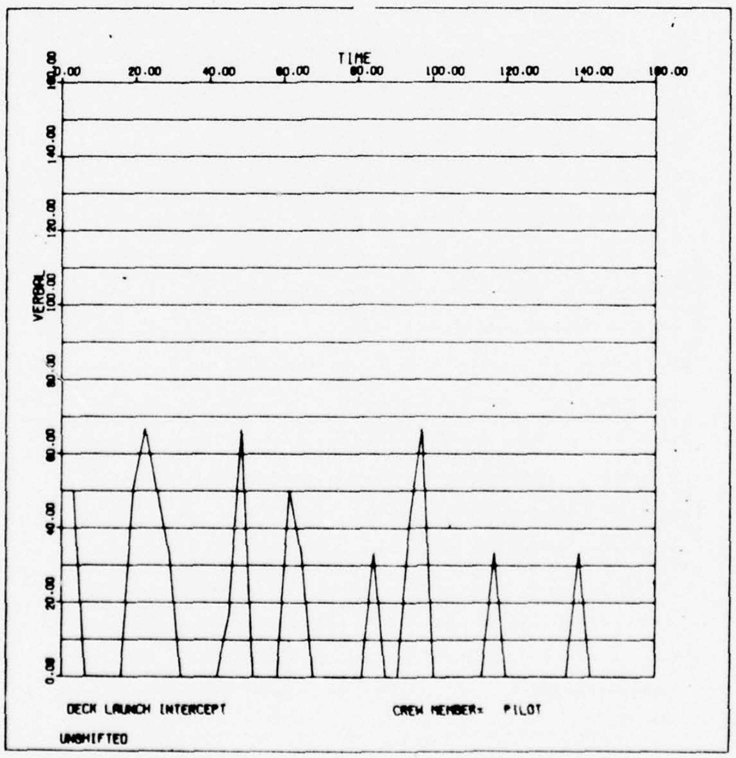

FIGURE 2.3-25: VERBAL WORKLOAD TIME HISTORY

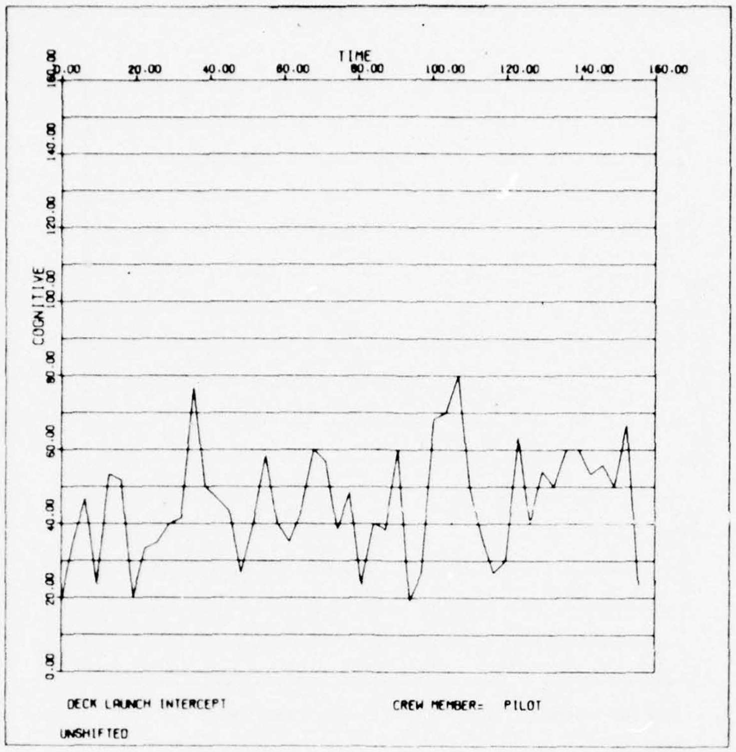

FIGURE 2.3-26: COGNITIVE WORKLOAD TIME HISTORY

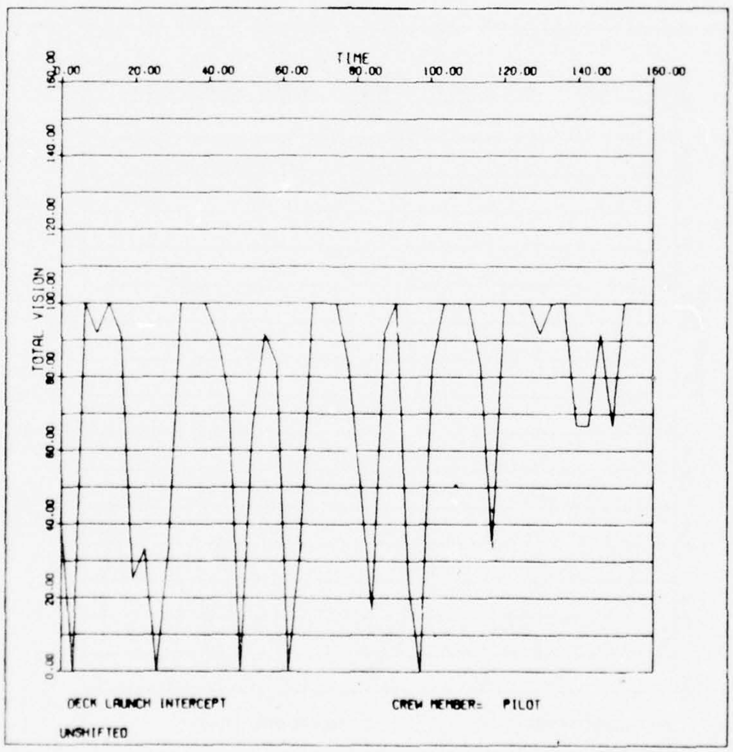

FIGURE 2.3-27: TOTAL VISION WORKLOAD TIME HISTORY

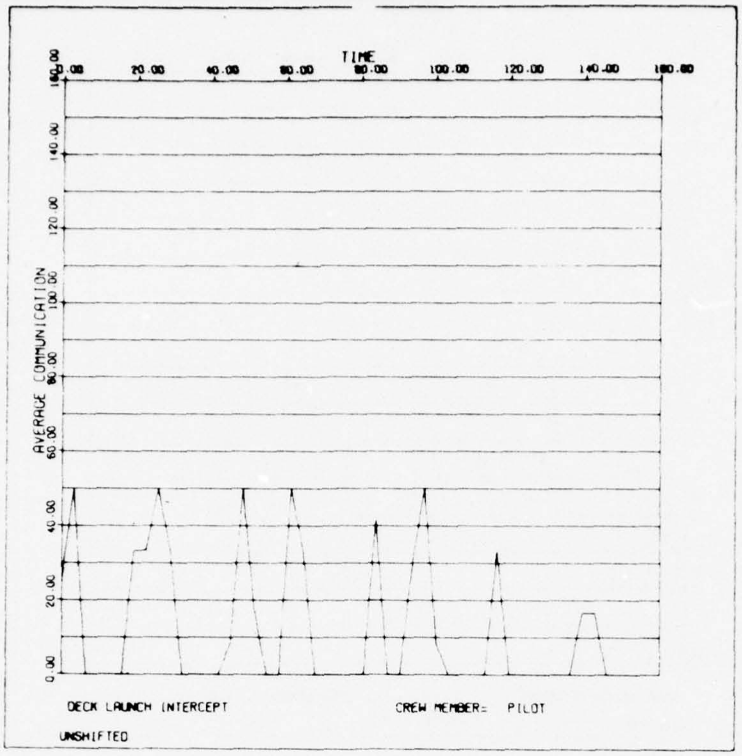

FIGURE 2.3-24: AVERAGE COMMUNICATIONS TIME HISTORY

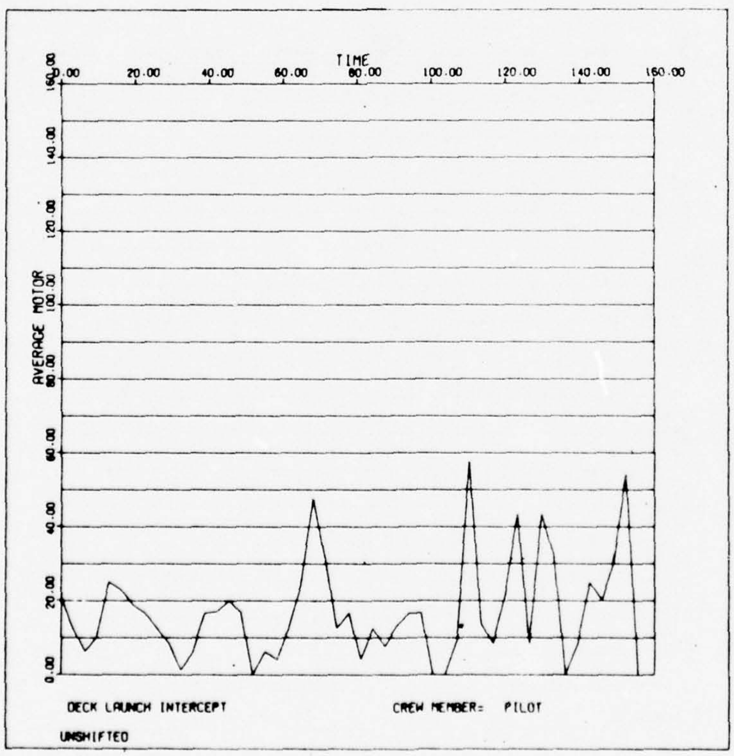

FIGURE 2.3-29: AVERAGE MOTOR TIME HISTORY

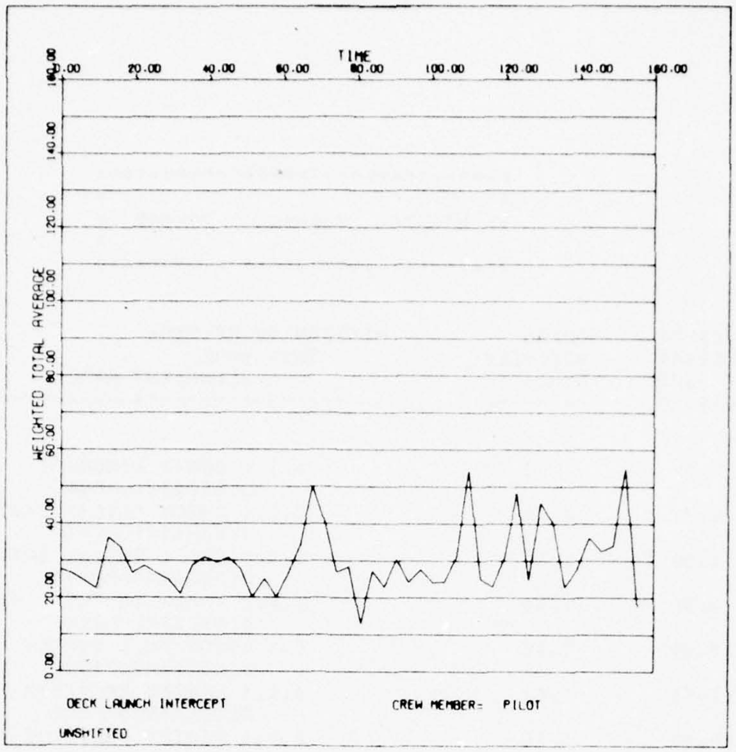

FIGURE 2.3-30: WEIGHTED TOTAL AVERAGE TIME HISTORY

TASK/CHANNEL ACTIVITY VERSION=STANDARD

CREWMAN 1 PILOT TIME INTERVAL 576 TO 582 THRESHOLD 80PERCENT

TASK ID	TIME	PCNT	TIME	PCNT	TIME	PCNT	TIME	PCNT	TIME	PCNT
	EXT VISION		INT VISION		RIGHT HAND		LEFT HAND		RIGHT FOOT	
5.4 CHECK THREAT + WARN SET	.0	0	1.0	17	.0	0	.0	0	.0	0
9.26.1 SELECT SBOTHS	.0	0	2.0	33	2.0	33	.0	0	.0	0
8.10.1 SELECT STORES	.0	0	2.0	33	.0	0	2.0	33	.0	0
8.10.1 SELECT STORES	.0	0	1.0	17	.0	0	1.0	17	.0	0
TOTAL	.0	0	6.0	100	2.0	33	3.0	50	.0	0

TASK ID	LEFT FOOT		COGNITIVE		AUDITORY		VERBAL	
5.4 CHECK THREAT + WARN SET	.0	0	.2	3	.0	0	.0	0
9.26.1 SELECT SBOTHS	.0	0	.6	10	.0	0	.0	0
8.10.1 SELECT STORES	.0	0	.6	10	.0	0	.0	0
8.10.1 SELECT STORES	.0	0	.3	5	.0	0	.0	0
TOTAL	.0	0	1.7	20	.0	0	.0	0

FIGURE 2.3-31: CHANNEL ACTIVITY REPORT

MISSION SCENARIO REPORT

TIME INTERVAL (SEC) SINCE MISSION START BEGINNING	END	TOTAL ACTIVITY TIME	MISSION EVENT NAME / TASK NAME / SITUATION NAME
.00	3.00	3.00	8.1.1 ORBIT AIRCRAFT CLOSEAIRSUPPORT
3.00	6.00	3.00	5.2.1 CHECK FLIGHT INSTRUMENTS CLOSEAIRSUPPORT
6.00	8.00	2.00	5.3.1 CHECK ENGINE INSTRUMENTS CLOSEAIRSUPPORT
8.00	9.50	1.50	5.4.1 CHECK THREAT + WARN SET CLOSEAIRSUPPORT
10.00	12.00	2.00	5.5 CHECK FUEL SUPPLY CLOSEAIRSUPPORT
17.00	18.50	1.50	8.2.1 VERIFY PREVIOUS SELECTION CLOSEAIRSUPPORT
19.00	20.50	1.50	8.2.1 VERIFY PREVIOUS SELECTION CLOSEAIRSUPPORT
21.00	23.50	2.50	8.2.3 SELECT CONTROL MODE CLOSEAIRSUPPORT
25.00	31.00	6.00	8.2.4 TRANSMIT UHF CLOSEAIRSUPPORT
32.00	44.00	12.00	8.2.5 RECEIVE UHF CLOSEAIRSUPPORT
44.00	48.00	4.00	8.2.4 TRANSMIT UHF CLOSEAIRSUPPORT
48.00	52.00	4.00	8.2.5 RECEIVE UHF CLOSEAIRSUPPORT
53.00	59.00	6.00	8.2.4 TRANSMIT UHF CLOSEAIRSUPPORT
59.00	61.00	2.00	8.2.5 RECEIVE UHF CLOSEAIRSUPPORT
63.00	73.00	10.00	8.2.6 DETECT FAC (A) CLOSEAIRSUPPORT
74.00	77.00	3.00	8.2.4 TRANSMIT UHF CLOSEAIRSUPPORT
77.00	78.00	1.00	8.2.5 RECEIVE UHF CLOSEAIRSUPPORT
82.00	88.00	6.00	8.2.4 TRANSMIT UHF CLOSEAIRSUPPORT
88.00	91.00	3.00	8.2.5 RECEIVE UHF CLOSEAIRSUPPORT
91.00	94.00	3.00	8.2.4 TRANSMIT UHF CLOSEAIRSUPPORT
94.00	99.00	5.00	8.2.5 RECEIVE UHF

FIGURE 2.3-32: MISSION SCENARIO REPORT

2.3.5.3 (Continued)

may indicate a need for reallocation of man-equipment functions, or inter-crew man functions and tasks, or of interchannel tasks.

Task activity identifies those time segments in which the specified channel, or average workload exceeds a specified threshold value. In each of the time segments, the threshold equals or exceeds a specified value, the entire list of tasks, by identifier, name and time per channel, is printed out (Figure 2.3-31). This analysis identifies for the human factors engineer the factors which have contributed to the critical overload situation. This allows the analyst to judge the efficacy of restructuring or reallocating tasks to improve operating procedures.

Subsystem activity can be broken out and reported in two separate reports (although this was not required or produced for the analysis used as an example herein). The first identifies those activities associated with a given subsystem during a specified period of time. The second prints out subsystem activity during critical overload periods when individual channel or average workloads equal or exceed a preassigned threshold level. The subsystem activities are generally of interest during detailed examination of small segments of mission operations, e.g. critical phases of attack phases or weapons delivery, or approach/landing portions with unusually high workloads and concentrated activities.

Mission scenario outputs consist of a chronological listing of mission tasks, the time each task is started and the time each task ends. A partial listing is shown in Figure 2.3-32.

The statistical calculations are a carryover from a previous program developed at Boeing named Workload Evaluation of Cockpit Crews. The calculations presently done are the same as for Workload Evaluation of Cockpit Crews: Average workload and standard deviations for each of the eight channels, cumulative workload for (1) total vision, (2) total motor, (3) total communications and (4) average of the eight channels. Individual channel averages are defensible and useful, and some cross-

2.3.5.3 (Continued)

channel average may be meaningful. A user option may be desirable, rather than an overall evaluation (e.g., combining eye and feet activity for "average" workload).

2.3.5.4 Workload Assessment Model Relationship to Baseline HFE Methodology

WAM application tracks directly with the manual procedure described with the baseline process (and summarized briefly in introductory material early in this section). It adds considerably in quantitative precision and in credibility of results. It also provides significantly improved appraisals for possible workload shifting through the channel comparisons - for example, an overload for the right hand might be adjusted by shifting tasks to the left hand. Individual channel data are useful and defensible, as are:

- o Average workload and standard deviations indicating load variations during the mission segment for each channel
- o Cumulative workload for total vision, total communication
- o Task printouts for overload areas, and
- o Scenario summary data

The utility of averaging all eight channels may be debatable - it does provide a better impression of the net "loading" the crewman may react to.

The main requirement for WAM refinements is in the data area - to develop a data bank of broadly applicable task times.

2.3.6 Computer Aided Design of Crew Stations (CAD)

2.3.6.1 General Computer Aided Design Concept

The Computer-Aided Design (CAD) model provides a set of computer routines to assist in various aspects of crewstation design. CAD encompasses a mix of capabilities to be used individually or collectively in the development and evaluation of crewstation designs. In other words, the separate functions of CAD can be applied somewhat independently as needed to support a particular phase of design development. For example, CAD can be employed for a crewstation vision analysis in one instance or a reach analysis in another instance. Design development status and user operations for each CAD function are summarized below:

Crewstation Geometry Description

CAD will now accommodate a complete geometric description of a crewstation; e.g. aircraft cockpit. This capability is basic to computer-aided design because a crewstation configuration must first be stored in a computer before it can be modified, analyzed or otherwise affected.

Geometric aspects in a crewstation are described simply as lines, vertices of polyhedrons, or conic sections. The CAD user assigns a name and then defines a set of coordinate points or conic parameters to establish the shape and location of the object in the crewstation. Locations are specified relative to the overall crewstation coordinate system. Geometric objects can be organized under named subsystems or control and display panels. The format for data input is consistent with the CAFES Data Management System and it is designed for maximum user ease.

Crewstation Coordinates Conversion

CAD has the capability to perform transformations of coordinate values between coordinate systems, but this function is not of direct concern to the user. The user is not exposed directly to this function, i.e. he is not required to input transformation data or commands. The function is provided within the computer for his convenience. For example, individual controls and displays in a cockpit can be located by two-dimensional panel

coordinates rather than by an overall three-dimensional coordinate system. This feature can also be used to automatically describe geometric items in a different coordinate system if a user prefers to make such a change.

Crewstation Scaling

Geometric items can be automatically scaled (uniformly expanded or contracted) inside the computer by simply issuing a scaling command. The scaling command for CAD is expressed by the percentage increase or decrease desired.

Crewstation Tailoring

CAD now provides the user with the capability for making selective changes in a crewstation geometry description. For example, an instrument can be relocated or a panel reshaped or repositioned by simply issuing a DELETE command for the item of interest and writing a new description for the item. Changes inside the computer will occur only for the item being modified - the remaining crewstation remains undisturbed. This tailoring function allows rapid update of a crewstation design.

CAD tailoring also provides for redefinition of crewstation subsystems. For example, the user may wish to build-up a subsystem description by piece-meal definition of various items and then combine them later under one subsystem (for easy reference in subsequent analyses and report commands). This is accomplished with the simple REDEFINE command followed by a list of the items to be combined.

Panel Space Allocation/Control and Display Arrangement

Allocation of panel space and arrangement of controls and displays is part of the current development. Initial development provides means for easily specifying a detailed panel arrangement or changes to that arrangement. These means are incorporated in the functions for crewstation geometry description, crewstation tailoring, and digitizer input of crewstation geometry. The allocation and arrangement function is further supported by the reach analysis and section view features of CAD.

2.3.6.1 (Continued)

Vision Analysis

CAD will now perform a crewstation vision analysis. Employment of this function for external vision analysis requires the user to specify (1) what geometric objects are opaque; (2) What objects are transparent, and (3) location of the eye reference point. These are easy tasks, once the crewstation configuration has been stored in the computer.

Internal vision analysis is accomplished via same elements involved in the reach analysis program, i.e.: the data structure for input of vision angular and distance limits is the same as for the reach envelope input. All of the internal vision analysis requirements can be met by appropriate operation of the reach analysis procedure. For example, locations of vision distance limits on specified panel surfaces can be found by inputting a constant-reach envelope (at the fixed vision distance).

Reach Analysis

The CAD reach analysis function is now operating. When the user specifies a reach envelope, from measured anthropometric data available in the literature, the computer will (1) plot an instrument panel and designate points that can be reached, and (2) report in tabular form a distance comparison between actual reach and specific panel locations. Reach analyses for various-sized crewmembers are performed by specifying a different reach envelope for each "percentile size". Once a standard set of realistic reach envelopes are defined and input to the computer, then the user can, at any future time, simply command a reach analysis for any crewstation configuration. The only input data needed to generate a reach analysis are (1) a selection of percentile size, (2) a selection of panels, whose geometry has been previously stored, to be subjected to reach analysis, and (3) a section of reach reference point.

2.3.6.1 (Continued)

Crewmember Escape Analysis

CAD performs escape clearance analysis and this capability has been demonstrated by a sample problem exercise (Reference 28). In essence, this function checks for potential instances where a crewmember would bump into an object as he ejects from a crewstation. The user supplies an escape envelope (Volume of space through which the crewmember travels) and a list of crewstation objects to be checked. The computer automatically identifies potential interferences, degree of interference, and objects causing interference. A plan view drawing is also produced in addition to the tabular output.

Operation of the escape analysis feature is relatively simple and potentially can be made even easier by developing a Crewstation Geometry Evaluation Model capability to generate escape envelopes. Such a capability would allow a quick definition of escape volumes for various sized crew members and various seat orientations (ejection vectors).

Although specifically designed for computer-aided analysis of crewmember escape from an aircraft cockpit, the escape interference feature can be applied to any problem of fitting a defined volume into a complex and confined crewstation space.

Section Views

Original plans for CAD included provision for computer plots of section views. However, this capability already resides in the Crewstation Geometry Evaluation Model and a decision was made to take advantage of that feature when the Crewstation Geometry Evaluation Model is integrated in CAFES. The Crewstation Geometry Evaluation Model also provides perspective views which can be valuable for visualizing the overall crewstation geometry.

For more detailed information on design and operation of the various CAD functions, the reader is referred to the User's Guide (Reference 28).

2.3.8.2 (Continued)

Computer-Aided Crewstation Design Model Inputs

Three modes of geometric data input were exercised during initial CAD development: manual; digitizer; and the Crewstation Geometry Evaluation interface. The manual mode involves writing down, by hand, a point-by-point description (e.g., from a design drawing). The digitizer mode simply involves laying crosshairs on a drawing and pressing a button at appropriate locations. The CGE interface mode automatically interprets geometric data prepared for the CGE so that it can be input directly to CAD. To date, each mode has been demonstrated to function properly and the digitizer mode produced time savings of about 90% compared to the manual mode. Further development of the digitizer mode could provide for automatic formatting of geometric items into subsystems, panels, etc.

COMPUTER AIDED DESIGN OF CREW STATION MODEL OUTPUTS

Escape Interference Analysis

Crewmember Escape Analysis. A list of items which penetrate the escape volume, including location of penetration, depth of penetration, name of penetrating item, name of item being penetrated. A plot of escape interference features.

Panel, Control and Display Arrangement Drawings

Crewstation Geometry Data. Coordinate location of elements (instruments, displays, controls), items (points, lines, curves, planes, 3-dimensional surfaces) panels, and subsystems (within defined coordinate system) as modified by crewstation scaling, tailoring and/or coordinate conversion.

Vision Analysis

External Vision Polars. Location of opaque and transparent areas are provided for angular limits of $\pm$ 180° azimuth and $\pm$ 90° elevation.

Vision Distances. Distances between vision analysis reference point and points on a panel surface are determined for specified angles of azimuth and elevation or points on the panel surface.

2.3.6.1 (Continued)

Vision-Panel Intersection. Specifies the location of vision angular or distance limits on panel areas within the given vision angular limits (as a function of location of origin for vision analysis reference point).

Reach Analysis

Reach Deviations. Difference in distance between reach limits and cockpit locations specified as plus and minus distances and percentage of total reach. Provided for right and left hands and feet as a function of crewmember size and location of origin for reach envelope reference point.

Reach-Panel Intersection. Loci which define the intersection between reach envelopes and user-specified instrument panels.

The drawings and concomitant stored data on geometry not only provide a basis for comparing candidate systems, but also provide the basis for modifying the present system for application to a new or different development system with different mission or crewstation requirements. The historical development of design data and development criteria can be readily preserved by incorporation in a master storage and retrieval submodel.

Computer-Aided Crewstation Design Model Applications

Similarly to WAM, CAD applications are simple and straightforward. Outputs are examined to determine if vision, reach intersections, and escape volumes are reasonable and acceptable. Iterative refinements are accomplished as necessary to develop a suitable preliminary design or modify an existing design.

2.3.6.2 Computer Aided Design Requirements Specification

The specification for CAD is extensively long and detailed, so that replication herein would be excessive. The preceding concept description is fully and directly responsive to the specification to convey a summary of the requirements. A fully detailed development is provided in Reference 27 and 28.

2.3.6.3 Computer Aided Design of Crew Stations Relationship to Baseline HFE Methodology

Model elements for CAD of Crew Stations relate directly supporting to the types of requirements described in paragraph 2.2.1.10, Crew Station Configuration Concepts, Trade-Offs and Design. Referring to that paragraph will make apparent the fact that a number of additional elements might be specified and added. Some of the elements already exist in CGE but might be more effectively used in CAD (e.g., Military Standards). Others that will be useful are under development (e.g., Crewstation Assessment Reach), which will improve on the Reach evaluation. The overall process is quite complicated, and could require development of a separate baseline methodology to define a series of computer aids for detail design similar to the CAFES series for HFE uses.

While many other growth areas could be readily identified, the key emphasis in CAD has been to assure the designer has maximum flexibility to be responsive to all requirements, trade-offs and necessary compromises. Accordingly, the model is most extensively an aid for Layout Development and Evaluation.

CAD provides for rearranging an existing crew station with displays, controls and work space arrangement or developing a new one. It features the flexibility to be fully adaptable to any geometric shape. It includes the ability to reflect appropriate equipment space as equipment locations are designated. It can readily provide the capability to identify and locate dedicated panel areas, and many other features that might be useful to the designer.

Three major areas of development would be useful for CAD:

1. A catalogue of equipment dimensions data should be implemented at an early date.
2. Layout optimization routines should be started to incorporate the various constraints that are integrated by the designer in relating standards, area layout, usage characteristics, and criticality.

2.3.6.3 (Continued)

3. Interactive Graphics operations by the designer would be useful. However, these routines should include the results of (2) above.

2.3.7 Crewstation Geometry Evaluation (CGE)

The process of incorporating this model in CAFES is presently in progress. Related activities will provide a more current ability to produce information relevant to the present study. Accordingly, this section provides an initial summary, with more detailed data to result from the integration process.

2.3.7.1 Crewstation Geometry Evaluation Concept

The Cockpit Geometry Evaluation Computer Program System is designed and developed to be a computerized anthropometric evaluation tool available from the conceptual phases of crew station design. The heart of the evaluation method consists of a three-dimensional man-model (BOEMAN) (See Figure 2.3-33) that synthesizes joint locations and orientations as it simulates human movement. It can indicate and help resolve physical incompatibilities between any sized crew member (in percentiles) and the given crew station design beginning with the conceptual phases of product development. It appears that the concept may be flexible enough to be modified in the future to serve as a computer aided design tool as well as an evaluation tool.

The Crewstation Geometry Evaluation Computer Program System is a sequential set of FORTRAN IV programs for the CDC 6600/CYBER 74 that provides the capability to:

1. check, transform and store large and varied amounts of data,
2. retrieve selected subsets of data; calculate body joint locations of the man-model as it simulates task performance,
3. calculate selected numerical performance indicators,
4. determine whether the tasks are within the reach capabilities of any sized pilot under various restrained conditions,
5. detect visual or physical interference,
6. attempt to correct for visual interference, and

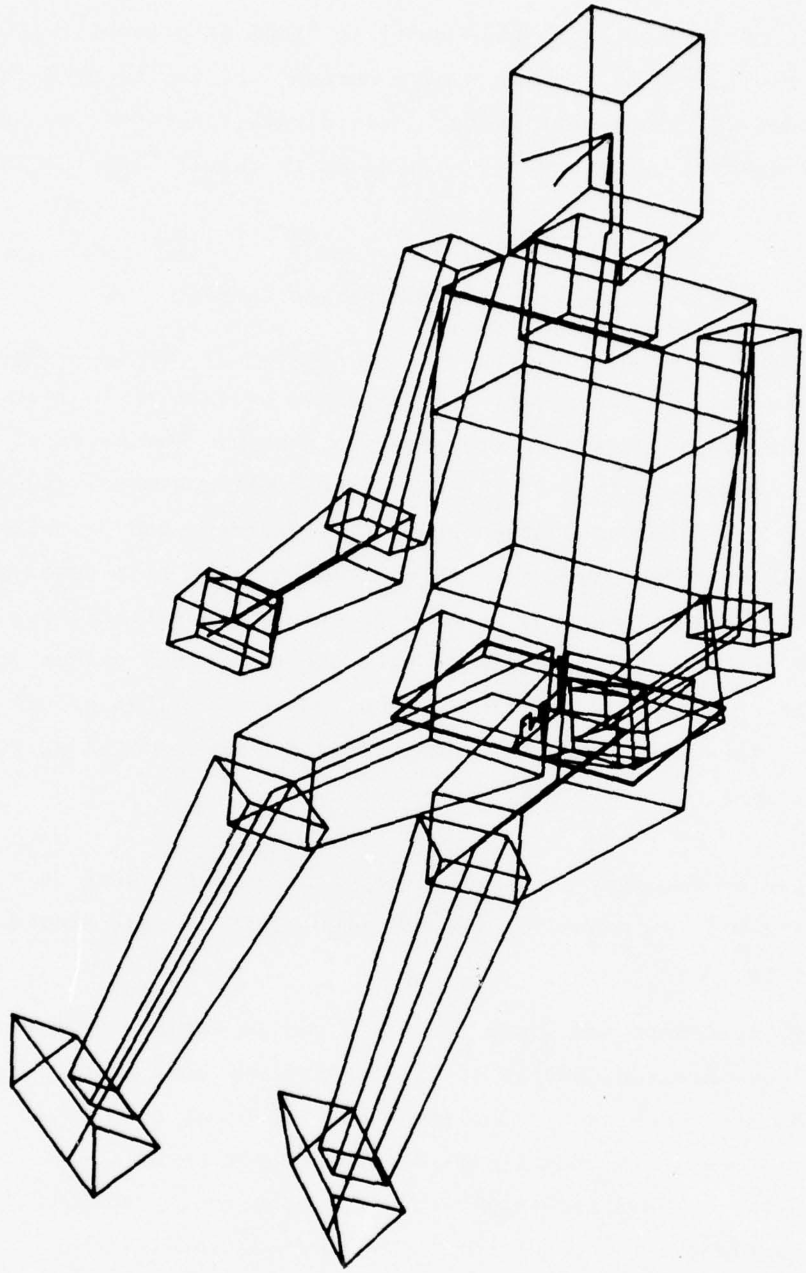

FIGURE 2.3-29: BOEMAN WITH LINKS AND BODY SEGMENTS IN STANDARD POSITION

2.3.7.1 (Continued)

7. avoid physical interference caused by straight line hand trajectories, independently check crew station compliance with selected military standards. These capabilities are an outgrowth of the requirements placed on the program during Phases I, IIA and III as well as various assumptions made in order that an operational evaluation tool would result.

2.3.7.2 Design Requirements and Features for Crewstation Geometry Evaluation Model Development

The Crewstation Geometry Evaluation Model program requirements and their relation to or effect on the Crewstation Geometry Evaluation Computer Program System consist of the following:

1. To establish a common reference system to evaluate the physical compatibility of an operator/crew station layout. In the program, three relatable reference systems are used. The first is a design coordinate system (using buttock, water and station lines). Data on cockpit geometry plane vertices and control locations are expressed in this reference system initially from crew station drawings. These are checked and transformed to a Euclidean coordinate system (x,y,z) whose origin coincides with the cockpit eye reference point. These data are then stored and made available for an evaluation run. At the beginning of each evaluation run, BOEMAN's eye midpoint initially coincides with the eye reference point origin. The data are again transformed so that the origin corresponds to the specified sized BOEMAN's seated position. The design coordinate system is necessary because the data are given in that system. The other two systems are used because the lumbar joint location (and hence the seat) are dependent upon BOEMAN's link dimensions if the eye midpoint is to be at the eye reference point.
2. To produce repeatable crew station evaluation results regardless of the investigator. Repeatable results depend on: universal availability of and well-defined procedures for generating the anthropological, geometric and flight mission data; consistent application of the model in regard to step size during a task sequence, error bounds, weighting

coefficients, and preferred angles (all of these relate to the objective function and to the entire optimization procedure used to synthesize BOEMAN's motion); relative insensitivity of the model to differing initial conditions brought about by utilizing a different computer.

3. <u>To permit crew station evaluations to be accurately performed using an acceptable amount of time and expense.</u> Hand joints with respect to the control locations are calculated with tolerance limits of 0.7 inch. Currently, on the basis of CDC 6600 computer time required to process a seven task sequence, joint position calculations and body segment locations (up to 14 positions per task) require, on the average, less than 2 minutes of central processor (CP) time per task. This can be further reduced significantly by decreasing the number of intermediate positions required in tasks of relatively small distance, for example.

4. <u>To permit specific items that interfere with crew movement to be identified and indicate areas where improvement is most beneficial.</u> The program uses bounded cockpit planes and planar approximations to the body segments of BOEMAN and tests each of them for the occurrence of visual interference with the line of sight at the end of each task. If visual interference occurs, a correction procedure is used to move the man-model to avoid the blocking plane(s) if he can feasibly do so. Physical interference of body segments with each other or with the crew station is identified and its extent and importance are assessed. Physical interference correction is handled partially by avoiding interference of objects with the hands and/or feet as they travel towards their specified control points.

5. <u>To permit the evaluator to consider dynamic motion with real time</u> effects, variations in operator size, simple and complex action and physical restraints. Presently the Cockpit Geometry Evaluation Computer Program System utilizes task data that simulates the duration of a human motion and the generated positions correspond to this time interval. The individual length and mass percentiles of the body segments are user specified, providing for size and weight variations

of the operator. Physical restraints such as lap belts or shoulder harnesses are currently provided for by restrictions on the angular limits of pertinent joints in the upper torso.

6. <u>To produce results in a form applicable to either program management or design development decisions</u>. The program produces a printed history of a flight mission portion (or task sequence) for evaluation. There are user-controlled options available to vary the size and content of the output depending on the purpose of the evaluation. The options include suppression of any or all input data, and expansion of the processing and summation sections. The system automatically provides for a minimum of printout when a task is performed feasibly. A summary of the evaluation run is also provided which reports the number of times a body system (e.g., upper torso, arms, feet, and head) had to move during the task sequence and provides a list of infeasibility conditions generated during the sequence.

7. <u>To provide a method for validation of the mathematical man-model and Crewstation Geometry Evaluation Computer Program System</u>. The validation in which comparisons of man-model and human paths of motion are analyzed is discussed in the validation Document (Reference 12). This consisted of an evaluation of the cockpit of the A7E fighter aircraft using the Crewstation Geometry Evaluation Computer Program System to determine if problems known to exist with this crew station were detected by the Crewstation Geometry Evaluation Computer Program System and whether other unreported problems also exist. The results of the A7E evaluation are discussed in Volume I of the Phase III final report (Reference 17).

<u>Inputs to Crewstation Geometry Evaluation Model</u>

The input required includes initial and final joint locations during the task, centroid percentiles and mass for each link, task control locations, and initial joint angular and position values. The joint location and orientation arrays, and the constraint vectors are reset for the next task with BOEMAN's current orientation and position.

2.3.7.2 (Continued)

Onput from Crewstation Geometry Evaluation Model

Program OUTGO, the output overlay, provides for a printed history of the evaluation run, data for graphs and charts, and an optional tape for the validation section. The printed history is divided into four parts:

1. Input data
2. Results of task sequence processing
3. Summation data
4. Summary of task sequence

Summation data include the numerical performance indicators calculated in the previous overlay (Program SUMM). The data required for validation include BOEMAN's joint locations during each step of a task for which comparable laboratory data exist. The task sequence summary consists of a table of the number of movements of each Body system and a summary of infeasible tasks during the sequence.

The printed history is generated using the intermediate output file along with control variables (user specified) which determine the amount and kind of history required for the evaluation.

2.3.8 Human Operator Simulation (HOS)

Detailed CAFES interfaces with the Human Operator Simulation are in initial exploratory phases. Accordingly, this section is mostly descriptive in nature.

2.3.8.1 General Human Operator Simulation Concept

The Human Operator Simulation Model is currently under development at NADC and is not currently part of the CAFES system library. The date of introduction has yet to be defined (Reference 39).

The Human Operator Simulation Model is a generalized computer-driven model of a human being in a goal-oriented task processing environment. The model has been under development over the past several years to enable simulation of human operator functions in weapons systems as realistically and accurately as the functions of weapons systems are simulated by models.

Those human operator simulations attempted to date show progress toward attainment of the realism and accuracy necessary to replace the human with the simulator. Normal task analyses, for example, leave one with the impression that a human operator serially processes all steps in a particular task as if this were the only one he had to perform. This approach ignores the dynamic, adaptive character of actual human behavior. In reality, the operator is usually processing a variety of more-or-less independent tasks simulataneously (e.g., maneuvering aircraft and searching visually for targets while monitoring instructions from the Forward Air Controller). Task analyses fails to indicate what factors determine when he stops working one task and begins to work on another. Such techniques yield oversimplifications on the role of the operator, thus providing questionable operator workload information. This is not to indicate the task analyses is useless or not effective. On the contrary, a task analysis does result in familiarity with the system and often reveals many shortcomings and areas of probable difficulty.

2.3.8 (Continued)

The method of entering data and the machine language to be used has been examined. A special Human Operator Procedures Language (HOPROC) has been developed to enable users of HOS to input both operating procedures for the system and mission instructions in English-like statements. HOPROC statements are "compiled" by HAL, the HOPROC Assembly/Loader program. The output of HAL is then input to HOS. HOS operates as a processor of the pseudo-machine instructions produced by HAL. Its logical processes are closely analogous to the logical processes of a human operator performing the same task, and the data it produces is amenable to the same type of analyses as are performed on data from a human experiment.

HOS has four principal program modules: The Decoder, the Multiplexer, the Estimator and the Banker.

2.3.8.2 Program Modules

The Decoder is analogous to the human understanding and decision-making function. It receives an instruction, comprehends it, and decides what further information and actions are necessary to accomplish it. It then initiates the necessary steps to obtain the information or perform the actions. This may involve the initiation of a new procedure when a display or control must be "enabled" before it can be used. It may require calls to the Estimator to obtain the estimated value of the device, to the Anatomy Mover to prepare the body for performing an action, or to the Control Manipulation Section of the processor. The Decoder thus determines what is needed and how best to sequence actions in order to accomplish it. It also determines whether a procedure can be continued. When a particular action cannot be performed immediately, it calls the Multiplexer to select another procedure to be executed.

The Multiplexer is the module that decides which procedure should be handled next by the Decoder. It establishes priorities among possible procedures and generates interrupts when an alteration in the instruction sequence is necessary. The Multiplexer can be called for any of three reasons:

2.3.8.2 (Continued)

1. If the sequence of instructions constituting a procedure is completed,
2. If an instruction is executed which permits the selection of a new procedure, or
3. If an action in a procedure cannot be completed.

The Multiplexer selects a new procedure by scanning the list of available procedures and selecting the one with the highest criticality. If none are sufficiently high, the Multiplexer may either return to the procedure that was being executed or enter a "relax" mode in which physical and mental conditions will be reflected in improved O-state levels. O-states are parameters which describe the individual operator's current capability to perform certain classes of operation. These may be permanent (such as basic ability) or transient reflecting physical or mental fatigue. Transient components of O-states will vary as a function of work and relaxation cycles.

A second type of interrupt is generated by hardware conditions that may affect the sequence of a run, such as the appearance of a warning light. Such events, however, may not affect the operator's actions immediately. An Interrupt Detector in the Banker determines the likelihood that the change in the hardware state will be noticed by the operator as a state which critically requires his attention.

The third type of interrupt occurs when, for example, the simulated operator requires his left hand to activate some device but he is currently using his left hand to adjust another control. The current procedure will be terminated and a scheduled interrupt arranged for when the left hand becomes free to be used by this procedure. In the interim the operator may work on other tasks.

The Estimator is the sensing/remembering core of HOS. It also determines the time costs for performing certain actions and for absorbing information. For instance, following a decision to set a knob at 0.5, the Estimator

might determine that it will take 0.8 seconds to absorb the information on the present position of the knob and 1.1 seconds to accomplish the knob-turn action.

The Estimator's function closely simulates a human being's actions in that its operations are not fully deterministic. The three kinds of actions are:

1. Preparation for information gathering, such as moving eyes to display,
2. Information absorption, such as recognizing the value indicated on the display, and
3. Control actuation, such as position of a lever.

Before performing a control actuation action, the operator checks to see if the action is necessary -- whether the control is already in the desired position. If it is, the action will not be taken. The check is performed by means of a sequence of information gathering actions on the value of the current control setting.

Information gathering is a four stage process. First if the operator is already "in contact" with the display or control of interest, he will absorb its value. Second, if he is not in contact with the device, recall is attempted, which if successful entails only a small time cost. If recall is not immediately possible, but still highly probable, the operator is allowed additional time to attempt recall. This results in the accumulation of additional small time charges until it is decided either that the value can be remembered or that recall has failed.

The success of any recall attempt is probabilistic, depending on:

1. The time since the previous observation, t
2. The hab strength, H
3. The short term memory capability, and
4. A confidence level, which reflects the operator's willingness to believe his own memory, and is the reference against which the probability of recall is tested for success.

2.3.8.2 (Continued)

The Banker accumulates time charges for all actions performed by the operator and serves as the interface with the hardware simulator. When a numerical value of a display reading or a control setting is required, the Banker acquires it from the hardware simulator, which may be either a data file or a hardware simulation program module containing the equations governing hardware response to control manipulations.

Charges also accrue in terms of aphysiological change (eye strain, muscle fatigue, etc.), reflected by changes in O-state value over time, although the Banker is only concerned with time charges.

The output from the simulator is a printout of information messages as each instruction is executed and whenever a significant event occurs. The user may also define certain processing points as milestones. When the milestone is reached, the data arrays associated with the displays, controls and functions are printed out.

The simulator also dumps the relevant data to a magnetic tape or disc for use by the Human Operator Data Analyzer/Collater (HODAC). HODAC reduces, formats and analyzes the data. The types of analyses which can be done include:

- o Display and Control usage -- including time spent accessing information, absorbing information, and monitoring.
- o Mediated function usage -- including time spent estimating and calculating.
- o Anatomy movement and memory.
- o Loading.
- o Procedural utilization.
- o Monitoring frequencies.
- o Interrupts.

The results of these analyses can be compared with mission scenario simulations, hardware and weapons systems simulations. These comparisons can be used to determine whether the events that transpired during an engagement were acceptable from both a human factors and an operational point of view.

3.0 CONCLUSIONS AND RECOMMENDATIONS

o Baseline Concept

The structured method developed herein to outline a baseline methodology for HFE processes provides for a logical and feasible sequencing of activities to support a system development program. With some additional effort, the baseline could be extended, organized, and documented to provide a reference source for broader applications which could draw more heavily and systematically from past experience for new development programs. This reference source would be useful in assuring improved consistency in HFE products between programs and in manual HFE efforts, as well as providing a structured format for CAFES uses. In either case, it would help to minimize attention to routine activities in order to concentrate more extensively on those activities that are unique to a present system development.

Most appropriate follow-up relative to this subject area would be to extend the baseline process developed during this study to cover an entire mission. Such a development should emphasize the systematic progression of analytic indenture to distinguish functions that are common to a system (e.g., aircraft) to a system type (e.g., fighter) and to specific variations in missions (e.g., reconnaisance, close support, air to air combat).

o CAFES Compatibility with the Baseline HFE Process and General Needs.

In general, CAFES submodel features, operations and requirements are compatible with the baseline process developed herein. Some refinements are desirable, most specifically with regard to improving user interface operations and interpretations.

A substantial effort still remains in the development of the CAFES system. The Computer Aided Crewstation Design Model is yet to be completed. The Crewstation Geometry Evaluation and the Human Operator Simulation Model are yet to be made compatible with the Data Management System so that all submodels can utilize and interchange input

and output information. Until this effort is accomplished, more extensive involvement of the HFE will be required to effect the interchange.

Verification and validation of CAFES submodels requires additional testing and use on both current and developmental systems. Sensitivity and ability of each submodel to discriminate significant differences have yet to be demonstrated. The influence of data, i.e., human operator reliability, equipment reliability, task performance time, etc., has yet to be established for both absolute and relative rankings of candidate crew system configurations.

A User's Guide to human factors engineering tasks, based on specific examples from previous systems developments is required to minimize required effort and to provide an efficient means to train personnel in the methods employed in human factors or crew systems analysis.

- General Data System Development Need

  Detailed development of a structured data system concept (i.e., an information system) is needed to provide for more effective data organization, storage, retrieval, integration and use. Properly structured, such a system could significantly enhance access to that minimum but sufficient level of detail necessary for HFE applications. This information system, built for a baseline methodology such as is reported herein, could significantly reduce or eliminate the need to start and develop new data sets for each new system development or modification to come along. With the systematic framework provided, and data updates maintained, appropriate information would be more readily accessible and usable throughout a research, development, test and evaluation program.

  Such an information system is considered highly desirable for manual analyses, and essential for the CAFES Data Management System (DMS).

3.0 (Continued)

A carefully developed structure for access to HFE data will have a significant influence in minimizing computer time and costs for data search in the DMS. Present formatting is compatible with the proposed concept; it remains to develop the information system. In all likelihood, this development can be most effective if accomplished to parallel or follow extension of the baseline process to encompass a total system concept. At a minimum, the resulting information system structure would be more appropriately postured for system development needs.

o General CAFES Applicability

CAFES related analyses or submodels applications are not limited to airborne weapons systems. Applications are currently being evaluated which are concerned only with HFE applications in handling of ground based equipment and materials that are completely divorced from either the airborne system or its support equipment. Such applications include: ground handling and sorting systems for postal envelopes and packages; the distribution, disbursement, and monitoring of airport passenger traffic in terminal areas, and fire department monitoring, disbursement, and control of fire fighting men and equipment leading to training requirements. The potential list is almost limitless since man is included in most systems as an information processor, decision maker and control actuator in response to the information processed.

o Specific CAFES Related Developments or Refinements

Information or data that can be stored to facilitate HFE-CAFES operations follow:

Mission Requirements

- Outline of system operational requirements
- Outline of mission scenario
- Mission profile data

3.0 (Continued)

Functional Flows

- System common functions (all aircraft)
- System type functions (e.g., fighter)
- Mission peculiar functions
- Task types: visual - motor - cognitive - auditory - verbal - other
- Task action elements
- Quantitative task features: time - accuracy - reliability
- Qualitative task data: pilot commentary - trade-off precautions - related hazard or accident potential
- Task characteristics and weighting information: task criticality ratings - task priority ratings - task adjustment data (mission stress, time compression) - task load rating
- Reference topics or sources

Equipment Data

- Physical characteristics: dimensions - weight
- Performance characteristics: parameters - accuracy
- Operator interface characteristics: interface features - tasks - task data as above
- Application characteristics: reliability - cost
- Location constraints: mandatory location - mandatory arrangement - mandatory access zones - options
- Use constraints: pilot commentary - unsatisfactory reports - other

Other Data

- Human anthropometry
- Life support data
- Other

Additionally, more specific CAFES model features are summarized in Table 3-1.

TABLE 3-1: CAFES, MODEL FEATURES AND REFINEMENTS SUMMARY

MODEL	CAPABILITY	INPUT REQUIRED	OUTPUT	LIMITATIONS	DESIRABLE REFINEMENTS, MODIFICATIONS
DMS	- store limited data - interchange data between models	instruction task data sequence data	reports - printed or graphical	- no bank of task data at present time - needs structure for HFE uses	- ability to access other storage system - transformation routines to use all models - develop information system concept for storage
FAM	allocate task order events	task list priorities time period	tasks: - ordered list - not started - not finished	- tasks identified - reliabilities known for men and equipment - task priorities and interactions	- develop task data - additional reliability data - tie directly to functions identified by mission scenario
WAM	- calculate workload	- tasks - events - channel activity	- workload statistics - plots of workload	- requires detail task and event list	- tie directly to functions identified via mission time line and functional flows
CAD	- depict crewstation layout - show escape volume and interference - show crewman reach capability	- crewstation geometry - crewman dimensions	- vision polar - escape plot - reach plot - crewstation layout	- basic elements requires dimensional crewstation - requires equipment catalog	- interaction graphics - instrument shape, sizes, stored for recall
CGE	- determine reach and visual capability for any size crewman	- crewstation geometry - crewman size - task sequence - visual target - limb location	- feasibility analysis - interference reports - MIL-STD compliance	- geometry defined - tasks defined	- modularize - streamline - update MIL-STD compliance check

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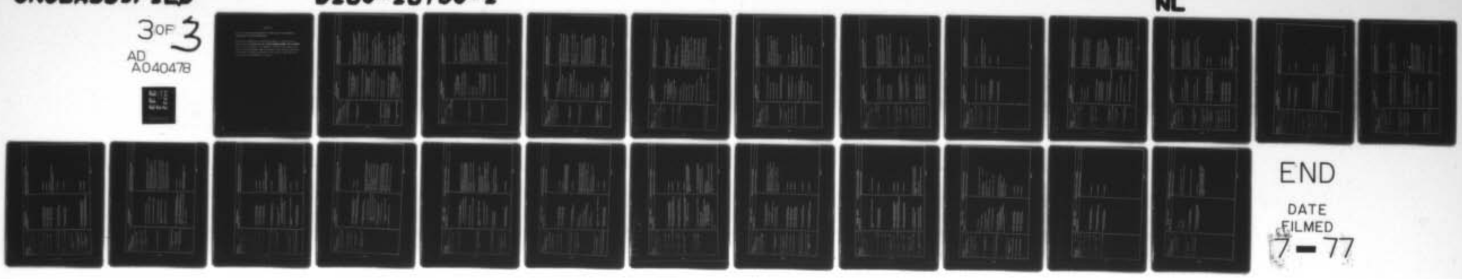

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APPENDIX A

DETAILED TABULATION OF REPRESENTATIVE FUNCTION-ACTION-INFORMATION REQUIREMENTS FOR RECEIVER REFUELING

This appendix summarizes a detailed development of function action-information requirements for one possible mission segment for a receiver vehicle-airial refueling. The summary is presented as an example, to show how such information might be developed. More extensive detailing of indentures is readily achievable if more specific implications for control-display requirements are desired.

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS 1.1.1 ACQUIRE RENDEZVOUS STATUS		
1.1.1.1 Proceed to Rendezvous Area 1.1.1.1.1 Initiate/Control Flight Mode	- 1 Maintain Aircraft Configuration as Required	Normal Flight Modes
	- 2 Maintain Flight Profile as Required - 2.1 Maintain Course to Rendezvous Area - 2.2 Adjust Altitude as Required - 2.3 Adjust Speed as Required	 Rendezvous Area Coordinates: Best Route; Planned Route Best Cruise Altitude; Planned Cruise Altitude Best Cruise Speed; Planned Cruise Speed
1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	- 1 Operate Navigation-Guidance Subsystem	Navigation-Guidance Procedures; System Operation Status Positioning Accuracy; Position Latitude-Longitude; Course; ETA; Backup Modes
	- 2 Adjust/Maintain Propulsion Subsystem Operations	Propulsion Parameters; Normal Operating Range/Settings; Backup Modes
	- 3 Adjust/Maintain Power Subsystem Operations - 3.1 Monitor/Control Electrical - 3.2 Monitor/Control Hydraulic - 3.3 Monitor/Control Pneumatic	Power Subsystem Parameters; Normal Operations Ranges/ Settings; Backup Modes
	- 4 Adjust/Maintain Fuel Subsystems Operations	Fuel Reserves; Tank(s) in Use; Fuel Rate
	- 5 Adjust/Maintain Auxiliary Subsystem Operations	Auxiliary Subsystem Parameters; Normal Operating Ranges/Settings; Backup Modes
	- 6 Monitor Caution-Warning Annunciaters	Systems Status-Normal/Abnormal; Annunciated Subsystems; Related Procedures; Backup Modes
1.1.1.1.3 Acquire/Confirm Rendezvous Area	- 1 Confirm Rendezvous Coordinates	Destination Coordinates; Characteristics
	- 2 Confirm Position Coordinates	Position Fix, Coordinates
1.1.1.2 Establish Rendezvous Status		
1.1.1.2.1 Establish Rendezvous Area Flight Parameters	- 1 Acquire/Maintain Rendezvous Configuration	Flight Control-Mode Changes for Rendezvous Loiter/ Intercept Flight
	- 2 Acquire/Maintain Rendezvous Profile - 2.1 Acquire/Maintain Rendezvous Course - 2.2 Acquire/Maintain Rendezvous Altitude - 2.3 Acquire/Maintain Rendezvous Speed	 Preplanned Rendezvous Circuit: Track; Turns Preplanned Rendezvous Altitude, Altitude Profile Reference Speed; Speed Changes
1.1.1.2.2 Confirm Aircraft Subsystems Status	- 1 Monitor/Control Navigation Guidance	Position Relative to Rendezvous Circuit; Estimated Time to Intercept; Subsystem Status
	- 2 Monitor/Control Propulsion	Propulsion Parameters; Rendezvous Reference Settings; Backup Modes

SHEET 1

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS 1.1.1 ACQUIRE RENDEZVOUS STATUS 1.1.1.2. Establish Rendezvous Status 1.1.1.2.2 Confirm Aircraft Subsystems Status (CONT'D)		
	- 3 Monitor/Control Power - 3.1 Monitor/Control Electrical - 3.2 Monitor/Control Hydraulic - 3.3 Monitor/Control Pneumatic	Power Subsystem Reference Settings for Rendezvous Operations
	- 4 Monitor/Control Fuel	Fuel Reserves; Fuel Rate
	- 5 Monitor/Control Auxiliary Subsystems	Rendezvous Settings/Operations Requirements
	- 6 Check-Test Subsystem Status as Required	Check-Test Requirements, Procedures
	- 7 Monitor Caution-Warning Annunciations	Annunciated Subsystems Status, Impact, Procedures; Backup Modes
1.1.1.2.3 Confirm Rendezvous Status Established	- 1 Confirm Position	Position Latitude-Longitude vs Desired Position and Intercept Plan
	- 2 Confirm Course	Actual Course vs Desired Course
	- 3 Confirm Altitude	Actual Altitude vs Planned Altitude, Altitude Profile and Tanker Altitudes
	- 4 Confirm Speed	Actual Speed vs Planned Speed, Speed Profile and Tanker Speeds
	- 5 Confirm Aircraft/Subsystems Operability	
1.1.1.3 Initiate Tanker Search	- 1 Initiate/Maintain Visual Search Modes - 1.1 Perform Direct Visual Search - 1.2 Perform Aided Visual Search	Visual Field and Search Modes: Present Position vs Rendezvous Area Location; Visual Range; Distinctive Tanker Characteristics; Aided Visual Systems, Characteristics and Ranges; Threat Environment
	- 2 Initiate/Maintain Sensor Search Modes	Sensor Field of View and Search Modes; Sensor Security; Range; Present Position vs Rendezvous Area Location; Distinctive Tanker Characteristics; Threat Environment
	- 3 Perform Position Coordination Actions	Position - Course - Time Relationships; Required Communications Security; Threat Environment

SHEET 2

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS 1.1.1 ACQUIRE RENDEZVOUS STATUS 1.1.1.4 Confirm Refueling Subsystems Status		
1.1.1.4.1 Confirm Fuel Management Subsystem Status	- 1 Preplan Transfer Control	
	- 1.1 Check Fuel Available	Fuel Reserves; Transfer Requirements
	- 1.2 Check/Adjust Fuel Weight-Balance as Required	Weight-Balance Conditions Existing; Impact of Planned Transfer
	- 1.3 Complete Fuel On-Load Planning	Transfer Acceptance Procedures: Tankload Sequencing; Acceptable Variation
	- 2 Confirm Transfer Systems Operable	Configuration Options; Operability Checkout Procedures; Coordination Requirements; Degraded Mode Effects, Procedures
1.1.1.4.2 Confirm Interaircraft Subsystem Status	- 1 Perform Subsystem-Display-Control Checks	
	- 1.1 Perform Checklist Operations	Operability Checkout Procedures; Desired Configuration, Options
	- 1.2 Verify Subsystem Operations as Feasible	Normal, Degraded Mode Effects, Procedures; Feasible Operating Modes
	- 2 Confirm Subsystem Operability	Confirmation/Coordination Requirements
1.1.1.5 Commence Loiter Operation	- 1 Maintain Prescribed Course	Rendezvous Area Routing Structure, Relative Position and Course
	- 2 Maintain Altitude	Procedural Rendezvous Altitude for Tanker and Receiver; Programmed Altitude Profiles
	- 3 Maintain Speed	Planned Speed Profile; Normal Speed Variations
	- 4 Maintain Subsystems Status	Normal/Abnormal Subsystem Variations and Trends; Specific Subsystem Abnormalities and Backup Modes
	- 5 Maintain Receiver Search	Available Search Modes, Ranges, Security and Security Requirements. Also Reference Function 1.1.1.3
1.1.1.6 Monitor Communications Subsystems		
1.1.1.6.1 Monitor Secure Channels	- 1 Monitor/Interpret Messages	Secure Channels, Codes, Modes, Procedures; Security Requirements for Operation
	- 2 Respond to Mission Related Messages - 2.1 Observe Security - 2.2 Provide Secure Answer - 2.3 Take Related Action	Secure Transmission Modes, Methods, Procedures

SHEET 3

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS 1.1.1 ACQUIRE RENDEZVOUS STATUS 1.1.1.6 Monitor Communications Systems (CONT'D)		
1.1.1.6.2 Monitor Open Channels	- 1 Monitor/Interpret Messages	Open Channels, Frequencies, Operating Procedures, Unique Mission Limitations and Constraints
	- 2 Respond to Mission Related Messages - 2.1 Observe Security - 2.2 Answer as Appropriate - 2.3 Take Appropriate Action	Communications Codes and Procedures
1.1.1.6.3 Monitor Other Channels	- 1 Monitor Intercom/PA/Other Messages	Locations, Access Modes
	- 2 Coordinate as Required	Coordination Requirements, Procedures
1.1.1.7 Maintain Life Support Status	- 1 Maintain Workspace Area	Crewstation(s); Relevant Task Requirements; Workspace Arrangement and Provisions
	- 2 Maintain Environmental Control	Occupied Areas; Periods of Occupation; Environmental Control Requirements; Modes and Ranges
	- 3 Maintain/Control Lighting	Ambient Lighting Range; Control Adjustment Range; Mission Related Constraints
	- 4 Maintain/Control Sanitation	Crew Number; Mission Duration(s); Sanitation Requirements, Provisions, Access
	- 5 Maintain/Control Sustenance	Crew Number; Mission Duration(s); Food, water uses, Storage, Preparation Requirements, Provisions, Access
	- 6 Monitor/Control Contaminant Levels	Contaminant Sources, Type, Hazards; Detection and Annunciation Modes; Suppression and Ventilation Modes and Procedures
	- 7 Monitor/Control Fire Detection/Suppressant	Fire Hazards, Prevention Methods; Detection-Location Isolation Methods; Suppressant Procedures
	- 8 Maintain Escape Systems Status	Escape Modes, Location(s), Accessibility, Procedures
OR 1.1.1.8 Proceed to Alternate Mission	----- Reference Function(s)/Actions for 1.5 Proceed to Alternate Mission	----- See Reference

SHEET 4

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS		
1.1.2 ACQUIRE TANKER/ESTABLISH INTERCEPT		
1.1.2.1 Maintain Rendezvous Status		
1.1.2.1.1 Maintain/Control Flight Parameters	- 1 Maintain/Control Aircraft Configuration	Configuration for Rendezvous Area Operation Flight Control Requirements
	- 2 Maintain Rendezvous Course	Present Position; Planned Rendezvous Course, Turns; Navigation, Flight Control Requirements
	- 3 Maintain Rendezvous Altitude	Present Altitude; Planned Rendezvous Altitude Profile; Collision Avoidance Procedures
	- 4 Maintain Rendezvous Speed	Present Speed; Planned Rendezvous Speed; Speed Profile Variations
1.1.2.1.2 Monitor/Control Aircraft Subsystems Status	----- Reference Function/Actions for 1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	----- See Reference
1.1.2.2 Acquire Tanker		
1.1.2.2.1 Maintain Tanker Search	----- Reference Functions/Actions for 1.1.1.3 Initiate Tanker Search	----- See Reference
1.1.2.2.2 Detect Other Aircraft	- 1. Acquire/Confirm Other Aircraft in Area	Probable Tanker Detection and Location; Other Aircraft Detection and Location
1.1.2.2.3 Confirm Aircraft Friendly	- 1 Visually Idenify Aircraft	Distinguishing Aircraft Characteristics, External Lighting Configuration
	OR	
	- 2 Electronically Identify Aircraft - 2.1 Interrogate Aircraft - 2.2 Verify Aircraft Response/Signature	IFF Operation Procedure; Communication Modes, Security Electronic Signature Characteristic
1.1.2.2.4 Confirm Aircraft as Tanker	- 1 Assume Tanker by Mission Plan	Time and Location vs ETA
	OR	
	- 2 Confirm Tanker Electronically	IFF Response; Communication Response
	OR	
	- 3 Confirm Tanker Visually	Visual Characteristic of Aircraft

SHEET 5

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS		
1.1.2 ACQUIRE TANKER/ESTABLISH INTERCEPT		
1.1.2.3 Execute Flight Intercept Mode		
1.1.2.3.1 Establish Flight Intercept Reference	- 1 Update Tanker Position - Course Data	Procedural Tanker Track, Turns and Projected Position
	- 2 Correlate Receiver Position - Course Data	Present Receiver Position Relative to Tanker Position; Projected Receiver Track
	- 3 Define Intercept Course	Optimum Intercept Course from Present Receiver Position to Projected Tanker Position; Practical Constraints; Intercept Course Plan
1.1.2.3.2 Acquire Intercept Flight Mode	- 1 Acquire Intercept Course	Intercept Course Plan; Flight Control Requirements
	- 2 Acquire Intercept Altitude	Planned Altitude Procedures, Profile
	- 3 Acquire Intercept Speed	Receiver Overtake and Tanker Matching Speed Requirements
1.1.2.4 Confirm Refueling Subsystem Status		
1.1.2.4.1 Confirm Fuel Management Subsystem Status	----- Reference Functions-Actions for 1.1.1.4.1 Confirm Fuel Management Subsystem Status, and	----- See Reference
	- 5 Initiate Procedural Checks	Procedure and Preliminary Fuel Management Checkout, Confirmation
1.1.2.4.2 Confirm Interaircraft Subsystem Status	-----Reference Functions-Actions for 1.1.1.4.2 Confirm Interaircraft Subsystems Status, and	-----See Reference
	- 3 Initiate Procedural Checks	Procedure for Preliminary Interaircraft Contact Subsystem Checkout, Confirmation
1.1.2.5 Monitor Communication Subsystems		
1.1.2.5.1 Monitor Secure Channels	-----Reference Functions/Actions for 1.1.1.6.1 Monitor Secure Channels	----- See Reference
1.1.2.5.2 Monitor Open Channels	-----Reference Functions/Actions for 1.1.1.6.2 Monitor Open Channels	----- See Reference
1.1.2.5.3 Monitor Other Channels	-----Reference Functions/Actions for 1.1.1.6.3 Monitor Other Channels	----- See Reference

SHEET 6

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.1 ACQUIRE TANKER RENDEZVOUS 1.1.2 ACQUIRE TANKER/ESTABLISH INTERCEPT		
1.1.2.6 Maintain Life Support Status	-----Reference Functions/Actions for 1.1.1.7	-----See Reference
OR 1.1.2.7 Execute Evasive Action	- 1 Initiate Defensive Activity	Type of Defensive Cover; Defensive Requirements, Procedures, Options
	- 2 Initiate Evasion Tactics	Options, Procedures for Evasive Action
OR 1.1.2.8 Continue Loiter Operation	-----Reference Functions/Actions for 1.1.1.5 Commence Loiter Operation 1.1.2.1 Maintain Rendezvous Status	----- See Reference
OR 1.1.2.9 Proceed to Alternate Mission	-----Reference Functions/Actions for 1.5 Proceed to Alternate Mission	----- See Reference

SHEET 7

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.2 PERFORM CLOSURE OPERATIONS 1.2.1 INITIATE CLOSURE PROCEDURES		
1.2.1.1 Acquire Intercept Position	- 1 Acquire Intercept Area	Intercept Area Latitude, Longitude, Course; Tanker Position, Course; Planned Intercept Position
	- 2 Confirm Position	Present Position, Course Relative to Tanker Intercept; Coordination, Confirmation Requirements
	- 3 Verify Tanker Proximity	Relative Tanker Position, Course, Flight Profile
1.2.1.2 Configure Receiver Profile/Subsystems		
1.2.1.2.1 Acquire Refueling Flight Mode	- 1 Acquire/Refine Aircraft Configuration	Required Receiver Configuration(s) for Smooth, Stable Tanker Overtake and Speed Match
	- 2 Acquire/Refine Refueling Heading	Planned Refueling Heading, Turns, Turn Locations
	- 3 Acquire/Refine Refueling Altitude	Planned Altitude Closure Profile
	- 4 Acquire/Refine Refueling Speed	Closing Speed Conditions: Tanker Reference Speed; Receiver-Tanker Range; Profile of Range-Range Rate Requirements and Speed Adjustments
	- 5 Confirm Flight Mode Established	Confirmation/Coordination Requirements
1.2.1.2.2 Monitor/Control Aircraft Subsystems Status	----- Reference Functions/Actions for 1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	----- See Reference
1.2.1.2.3 Verify Refueling Subsystems Status		
1.2.1.2.3.1 Verify Fuel Management Subsystem Status	- 1 Complete Checklist Procedures	Checklist Procedures; Operability Tests; Fuel Transfer Quantity-Rate Requirements; Unique Receiver-Tanker Transfer Characteristics
	- 2 Confirm Fuel Management Subsystem Configured	Pre-transfer Configuration Requirements; Coordination Requirements
1.2.1.2.3.2 Verify Interaircraft Contact Subsystem Status	- 1 Complete Checklist Procedures	Checklist Procedures; Operability Tests; Compatibility in Interaircraft Contact Subsystems (Probe, Receptacle); Required Flight Envelope Control for Transfer
	- 2 Confirm Interaircraft Contact Subsystem Status	Pre-transfer Configuration Requirements; Coordination Requirements

SHEET 8

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.2 PERFORM CLOSURE OPERATIONS 1.2.1 INITIATE CLOSURE PROCEDURES		
1.2.1.3 Acquire Gross Closure References	- 1 Confirm Tanker Identity	Distinguishing Tanker Features/Lighting; Useable Communication - Coordination Modes
	- 2 Acquire Relative Position/Path References	Relative Receiver-Tanker Location and Trends
	- 3 Confirm Relative Speed References	Receiver Speed Profile Requirements; Tanker Reference Speed; Range and Range Rate Profile Requirements
1.2.1.4 Monitor Tanker Separation/ Closure Status	- 1 Appraise Range - Range Rate	Relative Receiver - Tanker Range Separation and Closure Trends
	- 2 Appraise Relative Path-Course and Trends	Relative Receiver - Tanker Vertical-Lateral Separation and Closure Trends vs Distance
1.2.1.5 Monitor/Control Refueling Subsystems		
1.2.1.5.1 Maintain Fuel Management Subsystem Status	-----Reference, Maintain Functions/Actions for 1.2.1.2.3.1 Verify Fuel Management Subsystem Status	----- See Reference
1.2.1.5.2 Maintain Interaircraft Subsystem Status	-----Reference, Maintain Functions/Actions for 1.2.1.2.3.2 Verify Interaircraft Contact Subsystem Status	----- See Reference
AND 1.2.1.6 Monitor Communication Subsystems		
1.2.1.6.1 Monitor Secure Channels	-----Reference Functions/Actions for 1.1.1.6.1 Monitor Secure Channels	----- See Reference
1.2.1.6.2 Monitor Open Channels	-----Reference Functions/Actions for 1.1.1.6.2 Monitor Open Channels	----- See Reference
1.2.1.6.3 Monitor Other Channels	-----Reference Functions/Actions for 1.1.1.6.3 Monitor Other Channels	----- See Reference Also consider Coordination Modes Between Receiver and Tanker Airial Refueling Operator

SHEET 9

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.2 PERFORM CLOSURE OPERATIONS 1.2.1 INITIATE CLOSURE PROCEDURES		
1.2.1.7 Maintain Life Support Status	-----Reference Functions/Actions for 1.1.1.7 Maintain Life Support Status	-----See Reference
OR 1.2.1.8 Proceed to Alternate Mission	-----Reference Function(s)/Actions for 1.5 Proceed to Alternate Mission	----- See Reference
1.2.2 CAPTURE/CONFIRM INITIAL CLOSURE ALIGNMENT		
1.2.2.1 Maintain Receiver Flight/ Subsystems Stable		
1.2.2.1.1 Maintain Stable Flight Profile	-----Reference and Maintain Functions/Actions for 1.2.1.2.1 Acquire Refueling Flight Mode	----- See Reference
1.2.2.1.2 Maintain Aircraft Sub-systems Stable	-----Reference and Maintain Functions/Actions for 1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	----- See Reference
1.2.2.2 Acquire Receiver Closure Guidance		
1.2.2.2.1 Acquire Guidance References	- 1 Acquire/Monitor Range References	Reference Data and Cues for Relative Range, Range Rate and Trends
	- 2 Acquire/Monitor Vertical Closure Alignment References	Reference Data and Cues for Relative Altitude, Altitude Rate and Trends
	- 3 Acquire/Monitor Lateral Closure Alignment References	Reference Data and Cues for Relative Lateral Position, Position Rate and Trends

SHEET 10

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.2 PERFORM CLOSURE OPERATIONS 1.2.2 CAPTURE/CONFIRM INITIAL CLOSURE ALIGNMENT 1.2.2.1 Maintain Receiver Flight/Subsystems Stable (CONT'D)		
1.2.2.2.2 Monitor/Appraise Closure Status	- 1 Appraise Relative Range/Range Rate Trends	Relative Range, Range Rate, Hazards, Tolerances
	- 2 Appraise Relative Vertical Closure Alignment Trends	Relative Vertical Separation, Vertical Rate, Hazards, Tolerances
	- 3 Appraise Relative Lateral Closure Alignment Trends	Relative Lateral Separation, Lateral Rate, Hazards, Tolerances
1.2.2.3 Configure Receiver Refueling Subsystems		
1.2.2.3.1 Configure Fuel Transfer Management Subsystem	-----Reference, Maintain Functions/Actions for 1.2.1.2.3.1 Verify Fuel Management Subsystem Status	----- See Reference
1.2.2.3.2 Configure Interaircraft Contact Subsystem	-----Reference, Maintain Functions/Actions for 1.2.1.2.3.2 Verify Interaircraft Contact Subsystem Status, and	----- See Reference
	- 4 Acquire Transfer Position	Closure Preparation Procedures: Receptacle/Probe Status During Closure; Nominal Position/Status/Adjustments
	- 5 Verify Operability - Stability	Contact Subsystem Operability Checkout Procedures
	- 6 Maintain Nominal Targeting Position	Nominal Receiver Transfer Position Objective; Nominal Transfer Envelope Volume Boundaries; Unique Receiver Features; Peculiar Approach Control
1.2.2.3.3 Confirm Fuel Transfer Configuration Status	- 1 Coordinate Status	Coordination Requirements and Modes
1.2.2.4 Monitor Refueling Subsystems	- 1 Monitor Fuel Transfer Management Subsystem	Nominal Pre-Contact Status
	- 2 Monitor Interaircraft Contact Subsystem	Nominal Pre-Contact Status, Control Requirements

SHEET 11

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.2 PERFORM CLOSURE OPERATIONS 1.2.2 CAPTURE/CONFIRM INITIAL CLOSURE ALIGNMENT		
1.2.2.5 Monitor Communication Subsystems		
1.2.2.5.1 Monitor Secure Channels	-----Reference Functions/Actions for 1.1.1.6.1 Monitor Secure Channels	----- See Reference
1.2.2.5.2 Monitor Open Channels	-----Reference Functions/Actions for 1.1.1.6.2 Monitor Open Channels	----- See Reference
1.2.2.5.3 Monitor Other Channels	-----Reference Functions/Actions for 1.1.1.6.3 Monitor Other Channels	----- See Reference Also Consider Coordination Between Receiver and Tanker Aerial Refueling Operator
1.2.2.6 Maintain Life Support Status	-----Reference Functions/Actions for 1.1.1.7 Maintain Life Support Status	----- See Reference
AND/OR 1.2.2.7 Proceed to Alternate Mission	-----Reference Function(s)/Actions for 1.5 Proceed to Alternate Mission	----- See Reference
1.2.3 ITERATE INTERIM CLOSURE REFINEMENTS		
1.2.3.1 Maintain Receiver Flight/Subsystems Stable		
1.2.3.1.1 Maintain Stable Flight Profile	-----Reference and Maintain Functions/Actions for 1.2.1.2.1 Acquire Refueling Flight Mode	----- See Reference
1.2.3.1.2 Maintain Aircraft Subsystems Stable	-----Reference and Maintain Functions/Actions for 1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	----- See Reference

SHEET 12

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.2 PERFORM CLOSURE OPERATIONS 1.2.3 ITERATE INTERIM CLOSURE REFINEMENTS		
1.2.3.2 Refine Closure Guidance Response		
1.2.3.2.1 Refine Guidance Reference Accuracy	- 1 Refine Range Reference Information	Refined Reference Data Tolerances and Cues for Relative Separation Range, Range Rate
	- 2 Refine Vertical Closure Alignment Information	Refined Reference Data, Tolerances and Cues for Relative Vertical Separation and Vertical Rate Compared to Transfer Envelope Position
	- 3 Refine Lateral Closure Alignment Information	Refined Reference Data, Tolerances and Cues for Relative Lateral Separation and Lateral Rate Compared to Transfer Envelope Position
1.2.3.2.2 Appraise/Refine Closure	- 1 Appraise/Refine Relative Range/Range Rate	Nominal and Actual Range, Range Rate Profile, Acceptable Deviations; Magnitude of Control Requirement
	- 2 Appraise/Refine Relative Vertical Closure Alignment	Nominal and Actual Vertical Separation and Vertical Rate Profile, Acceptable Deviations; Magnitude of Control Requirement
	- 3 Appraise/Refine Relative Lateral Closure Alignment	Nominal and Actual Lateral Separation and Lateral Rate Profile; Acceptable Deviations; Magnitude of Control Requirement
1.2.3.3 Maintain Refueling Subsystem Status		
1.2.3.3.1 Monitor Fuel Transfer Management Subsystem	-----Reference and Maintain Functions/Actions for 1.2.1.2.3.1 Verify Fuel Management Subsystem Status	----- See Reference
1.2.3.3.2 Monitor/Control Interaircraft Contact Subsystem	-----Reference and Maintain Functions/Actions for 1.2.1.2.3.2 Verify Interaircraft Contact Subsystem Status, and 1.2.2.3.2 Configure Interaircraft Contact Subsystem, and	----- See Reference
	- 7 Monitor Dynamic Stability	Also consider Receiver-Tanker Dynamic Control Characteristics and Stability

SHEET 13

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.2 PERFORM CLOSURE OPERATIONS 1.2.3 ITERATE INTERIM CLOSURE REFINEMENTS		
AND 1.2.3.4 Monitor Communication Subsystems		
1.2.3.4.1 Monitor Secure Channels	-----Reference Functions/Actions for 1.1.1.6.1 Monitor Secure Channels	----- See Reference
1.2.3.4.2 Monitor Open Channels	-----Reference Functions/Actions for 1.1.1.6.2 Monitor Open Channels	----- See Reference
1.2.3.4.3 Monitor Other Channels	----- Reference Functions/Actions for 1.1.1.6.3 Monitor Other Channels	----- See Reference Also Consider Coordination Between Receiver and Tanker Aerial Refueling Operator
AND 1.2.3.5 Maintain Life Support Status	-----Reference Functions/Actions for 1.1.1.7 Maintain Life Support Status	----- See Reference
OR 1.2.3.6 Detect/Respond to Hazard	- 1 Detect/Appraise Closure Anomaly - 1.1 Detect Anomaly - 1.2 Confirm Anomaly Exceeds Parametric Bounds - 1.3 Identify Appropriate Procedure - 2 Institute Closure Stop-Restart Procedures	Nominal Conditions, Hazardous Deviations, Exceedance Detection/Annunciation Method/References Deviation Limits, Impact, Correction Needs Corrective Action Procedures Coordinated Separation Procedures and Profiles; Restart Point for Closure
AND 1.2.3.7 Reinstate Closure	- 1 Iterate Function 1.2.1, Iterate Interim Closure Refinements	-----See Reference
AND/OR 1.2.3.8 Proceed to Alternate Mission	-----Reference Function(s)/Actions for 1.5, Proceed to Alternate Mission	----- See Reference

SHEET 14

REFUELING-RECEIVER: FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS-RECEIVER		
1.3 PERFORM FINAL CLOSURE/CONTACT 1.3.1 PERFORM FINAL PRE-CONTACT ALIGNMENT		
1.3.1.1 Maintain Receiver Flight/ Subsystems Stable		
1.3.1.1.1 Maintain Stable Flight	-----Reference and Maintain Functions/Actions for 1.2.1.2.1 Acquire Refueling Flight Mode	----- See Reference
1.3.1.1.2 Maintain Aircraft Sub-systems Stable	-----Reference and Maintain Functions/Actions for 1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	----- See Reference
1.3.1.2 Precisely Track Guidance/ Control Trends	- 1 Monitor/Appraise Closure Status/Trends	
	- 1.1 Appraise Transfer Contact Envelope	Receiver Unique Nominal Contact Positioning Requirement and Tolerances: Envelope Volume Center and Boundaries
	- 1.2 Appraise Relative Range, Range Trend	Receiver Range, Closure Rate Requirements and Tolerances
	- 1.3 Appraise Relative Vertical Position, Vertical Trend	Receiver Vertical Position, Closure Rate Requirements and Tolerances
	- 1.4 Appraise Relative Lateral Position, Lateral Trend	Receiver Lateral Position, Closure Rate Requirements and Tolerances
	- 1.5 Appraise Receiver Position Stability	Relative Receiver-Tanker Stability in Path and Track: Attitude Perturbations Per Unit Time
	- 2 Acquire Precision Guidance Information	
	- 2.1 Provide Range-Range Trend	Required Precision Adjustments in Range Rate for Precise Envelope Acquisition and Control
	- 2.2 Provide Altitude-Altitude Trend	Required Precision Adjustments in Altitude, Altitude Rate for Precise Envelope Acquisition and Control
	- 2.3 Provide Lateral Position-Lateral Trend Connections	Required Precision Adjustments in Lateral Position and Rate for Precise Envelope Acquisition and Control
	- 3 Monitor/Confirm Closure Suitability	Relative Receiver-Tanker Positions, Stability

SHEET 15

REFUELING RECEIVER FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS - RECEIVER		
1.3 PERFORM FINAL CLOSURE/CONTACT 1.3.1 PERFORM FINAL PRE-CONTACT ALIGNMENT		
1.3.1.3 Acquire/Maintain Interaircraft Contact Position	- 1 Guide Receiver to Refuel Envelope	
	- 1.1 Confirm Nominal Envelope Position	Receiver Unique Envelope Position, Boundaries and Relative Stability
	- 1.2 Adjust Contact Subsystem for Clearance	Tanker Contact Subsystem Position and Stability Relative to Envelope Center Point and Boundaries
	- 1.3 Acquire Nominal Probe-Receptacle Position	Receiver Contact Subsystem Position and Stability Relative to Nominal Envelope Center Point and Boundaries
	- 2 Monitor/Confirm Receiver Stability	Receiver Position Stability, Attitude Perturbations Per Unit Time
	- 3 Confirm/Coordinate Contact Position Established	Interaircraft, Intraaircraft Coordination Requirements and Modes
1.3.1.4 Confirm Refueling Subsystem Status	- 1 Confirm Fuel Transfer Management Subsystem Readiness	Transfer Subsystem On-Off Status, Requirements Tanks-Valve Position Status Programmed Quantity Per Tank Transfer Subsystem Readiness
	- 2 Confirm Interaircraft Subsystem Readiness	Interaircraft Contact Subsystem Operability Status Interaircraft Contact Subsystem Readiness
	- 3 Confirm Tanker-Receiver Readiness	Receiver-Tanker Ready Status; Coordination Requirements and Modes
1.3.1.5 Establish Interaircraft Con-	- 1 Perform Hookup Operations	Contact Mode, Procedures, Interlocks
	- 2 Confirm Hookup Complete	Contact Confirmation Feedback; Coordination Requirements
AND 1.3.1.6 Monitor Communication Subsystems		
1.3.1.6.1 Monitor Secure Channels	-----Reference Functions/Actions for 1.1.1.6.1 Monitor Secure Channels	----- See Reference

SHEET 16

REFUELING RECEIVER FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS RECEIVER		
1.3 PERFORM FINAL CLOSURE/CONTACT 1.3.1 PERFORM FINAL PRE-CONTACT ALIGNMENT 1.3.1.6 Monitor Communication Subsystems (CONT'D)		
1.3.1.5.2 Monitor Open Channels	-----Reference Functions/Actions for 1.1.1.6.2 Monitor Open Channels	----- See Reference
1.3.1.6.3 Monitor Other Channels	-----Reference Functions/Actions for 1.1.1.6.3 Monitor Other Channels	----- See Reference Also consider: Possible Communication Through Contact Subsystem; Coordination Requirements Between Receiver and Airial Refueling Operator
AND 1.3.1.7 Maintain Life Support Status	-----Reference Functions/Actions for 1.1.1.7 Maintain Life Support Status	----- See Reference
OR 1.3.1.8 Detect/Respond to Hazard/Emergency	- 1 Detect Anomaly	Anomaly Discrimination; Detection-Annunciation Mode
	- 2 Appraise Criticality	Anomalous Condition(s); Subsystem(s) involved; Relative Hazard; Effect on Fuel Transfer Process
	- 3 Provide "Break Away"Alert	Alert Mode(s), Procedures, Coordination Requirements
	- 4 Institute Emergency Separation	Emergency Separation Path(s), Procedures
	- 5 Control Interaircraft Contact Subsystem	Avoidance of Tanker Subsystem - Receiver Clearance Needs
	- 6 Appraise Status	Anomaly Impact, Backup Modes
	- 7 Perform Corrective Action	Corrective Action Procedures; Results; Feedback; Receiver-Tanker Coordination
AND 1.3.1.9 Reinstate Closure	-----Iterate from Function 1.3, Perform Final Closure/Contact	----- See Reference
OR 1.3.1.10 Proceed to Alternate Mission	-----Reference Function(s)/Actions for 1.5 Proceed to Alternate Mission	----- See Reference

SHEET 17

REFUELING RECEIVER — FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS - RECEIVER		
1.4 COMPLETE FUEL TRANSFER 1.4.1 PERFORM FUEL TRANSFER		
1.4.1.1 Maintain Receiver Flight/ Subsystems Stable		
1.4.1.1.1 Maintain Stable Flight	-----Reference and Maintain Functions/Actions for 1.2.1.2.1 Acquire Refueling Flight Mode	----- See Reference
1.4.1.1.2 Maintain Aircraft Subsystems Stable	-----Reference and Maintain Functions/Actions for 1.1.1.2 Monitor/Control Aircraft Subsystems Status	----- See Reference
1.4.1.2 Maintain Precise Receiver Control	-----Reference and Maintain Functions/Actions for 1.3.1.2 *Precisely Track Guidance/Control Trends*	----- See Reference
1.4.1.3 Maintain Interaircraft	-----Reference, Maintain and Control Functions/Actions for 1.3.1.3 Acquire/Maintain Interaircraft Contact Position 1.3.1.5 Establish Interaircraft Contact	----- See Reference Also Consider: Interaircraft Contact Subsystem Operability Status; Interaircraft Coordination Requirements; Intraaircraft Coordination Requirements
1.4.1.4 Accomplish Fuel Transfer		
1.4.1.4.1 Operate Fuel Management Subsystem	- 1 Monitor/Maintain Fuel Management Subsystem Status	-----Reference Functions, Actions, Information for 1.3.1.4 Confirm Refueling Subsystem Status
	- 2 Confirm Ready to Transfer	Contact Status Information, Coordination
	- 3 Initiate Fuel Transfer	Fuel Flow Control Mode, Status Information
	- 4 Monitor/Control Transfer Subsystems Operations	
	- 4.1 Monitor/Adjust Fuel Pressure	Pressure Status
	- 4.2 Monitor/Adjust Fuel Flow Rate	Flow Rate Information
	- 4.3 Monitor Transferred Fuel Quantity	Fuel Transfer Status
	- 4.4 Maintain Fuel Weight Balance	Fuel Tank Quantities; Weight-Balance Procedures, Information
	- 5 Confirm Operations Normal	Nominal Operations; Anomoly Detection-Annunciation Modes
	AND/OR	

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REFUELING RECEIVER — FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS - RECEIVER		
1.4 COMPLETE FUEL TRANSFER 1.4.1 PERFORM FUEL TRANSFER 1.4.1.4 Accomplish Fuel Transfer 1.4.1.4.1 Operate Fuel Management Subsystem (CONT'D)	- 6 Detect/Respond to Abnormal Operations - 6.1 Detect Anomaly/Excessive Deviation	Aircraft/Subsystem(s) Anomaly Detection Modes(s), Identification, Annunciation
	- 6.2 Appraise Abnormality	Anomaly Effect on Flight Operations or Fuel Transfer; Subsystem(s) Involved; Potential Hazards
	- 6.3 Select Procedure	Abnormal/Emergency Procedures for Anomaly
	- 6.4 Provide Required Corrective Action	Break-Away Procedures; Corrective Action Procedures
1.4.1.4.2 Coordinate Interaircraft Transfer Status	- 1 Coordinate Fuel Transfer Status	Transfer Requirements, Rates, Progress
	- 2 Coordinate Contact Subsystem Status	Contact Position Status; Subsystem Operation-Control Status
AND 1.4.1.5 Monitor Communication Subsystems		
1.4.1.5.1 Monitor Secure Channels	-----Reference Functions/Actions for 1.1.1.6.1 Monitor Secure Channels	----- See Reference
1.4.1.5.2 Monitor Open Channels	-----Reference Functions/Actions for 1.1.1.6.2 Monitor Open Channels	----- See Reference
1.4.1.5.3 Monitor Other Channels	-----Reference Functions/Actions for 1.1.1.6.3 Monitor Other Channels 1.3.1.6.3 Monitor Other Channels	----- See Reference
AND 1.4.1.6 Maintain Life Support Status	-----Reference Functions/Actions for 1.1.1.7 Maintain Life Support Status	----- See Reference
OR 1.4.1.7 Detect/Respond to Hazard/Emergency	-----Reference Functions/Actions for 1.3.1.8 Detect/Respond to Hazard/Emergency	----- See Reference

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REFUELING RECEIVER	FUNCTION-ACTION-INFORMATION REQUIREMENTS	
FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS - RECEIVER		
1.4 COMPLETE FUEL TRANSFER 1.4.1 PERFORM FUEL TRANSFER		
AND 1.4.1.8 Reinstate Closure	- 1 Iterate From Function 1.3, Perform Final Closure/ Contact	----- See Referenced Sequence
OR 1.4.1.9 Proceed to Alternate Mission	-----Reference Function(s)/Actions for 1.5 Proceed to Alternate Mission	----- See Reference
1.4.2 PERFORM REFUELING DISCONNECT		
1.4.2.1 Maintain Receiver Flight/ Subsystems Stable		
1.4.2.1.1 Maintain Stable Flight	-----Reference and Maintain Functions/Actions for 1.2.1.2.1 Acquire Refueling Flight Mode	----- See Reference
1.4.2.1.2 Maintain Aircraft Subsystems Stable	-----Reference and Maintain Functions/Actions for 1.1.1.1.2 Monitor/Control Aircraft Subsystems Status	----- See Reference
1.4.2.2 Maintain Precise Receiver Control	-----Reference and Maintain Functions/Actions for 1.4.1.2 Maintain Precise Receiver Control	----- See Reference
1.4.2.3 Terminate Fuel Transfer Operations		
1.4.2.3.1 Confirm Transfer Complete	- 1 Verify Transferred Quantity Adequate - 2 Coordinate Transfer Complete	Receiver Requirement vs Total Fuel Transferred Confirmation, Coordination Transfer Adequate and Complete
1.4.2.3.2 Deactivate Fuel Management Subsystems	- 1 Deactivate Fuel Transfer Subsystem - 2 Appraise/Confirm Deactivation Complete	Deactivation Procedures Fuel Flow Stopped; Transfer Subsystems Shut Down

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REFUELING RECEIVER FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS - RECEIVER		
1.4 COMPLETE FUEL TRANSFER 1.4.2 PERFORM REFUELING DISCONNECT 1.4.2.3 Terminate Fuel Transfer Operations 1.4.2.3.2 Deactivate Fuel Management Subsystems (CONT'D)	- 3 Coordinate Status	Coordination Requirements Within, Between Vehicles
	OR	
	- 4 Detect/Respond to Anomaly	Anomaly Detection-Annunciation Methods/Modes; Response Procedures
1.4.2.3.3 Disengage Interaircraft Contact Subsystem	- 1 Deactivate Contact Interlocks	Interlock Status, Deactuation Procedure
	- 2 Confirm Disconnect	Interlock Status
	- 3 Stow Interaircraft Contact Subsystem	Separation, Stowage Procedure
	OR	
	- 4 Perform Abnormal Disengage Procedures	Abnormal Disconnect Conditions, Modes
1.4.2.4 Perform Separation Procedures	- 1 Confirm Disconnect Complete	Separation Completion Status Data
	- 2 Initiate Separation Procedures	Receiver-Tanker Separation Procedures
	- 2.1 Maintain Tanker Flight Stability	Tanker Course, Profile
	- 2.2 Initiate Receiver Separation	Receiver Course, Profile
	- 2.3 Confirm Separation Clearance Adequate	Separation Clearance Requirement
	- 3 Acquire Next Mission Phase	Planned Mission Phase
AND 1.4.2.5 Monitor Communication Subsystem		
1.4.2.5.1 Monitor Secure Channels	-----Reference Functions/Actions for 1.1.1.6.1 Monitor Secure Channels	----- See Reference
1.4.2.5.2 Monitor Open Channels	-----Reference Functions/Actions for 1.1.1.6.2 Monitor Open Channels	----- See Reference
1.4.2.5.3 Monitor Other Channels	-----Reference Functions/Actions for 1.1.1.6.3 Monitor Other Channels	----- See Reference

SHEET 21

REFUELING RECEIVER FUNCTION-ACTION-INFORMATION REQUIREMENTS

FUNCTIONS	RELATED ACTIONS	RELATED INFORMATION REQUIREMENTS
1.0 PERFORM REFUELING OPERATIONS - RECEIVER		
1.4 COMPLETE FUEL TRANSFER 1.4.2 PERFORM REFUELING DISCONNECT		
AND 1.4.2.6 Maintain Life Support Status	-----Reference Functions/Actions for 1.1.1.7 Maintain Life Support Status	--- See Reference
OR 1.4.2.7 Detect/Respond to Hazard/ Emergency	-----Reference Functions/Actions for 1.3.1.8 Detect/Respond to Hazard/Emergency	----- See Reference
AND 1.4.2.8 Proceed to Alternate Mission	-----Reference Function(s)/Actions for 1.5 Proceed to Alternate Mission	----- See Reference

SHEET 22

REFUELING RECEIVER FUNCTION-ACTION-INFORMATION REQUIREMENTS

Functions	Related Actions	Related Information Requirements
1.0 PERFORM REFUELING OPERATIONS - RECEIVER		
1.5 PROCEED TO ALTERNATE MISSION		
1.5.1 ACQUIRE NEXT MISSION LEG	- 1 Acquire Course	Planned Mission Leg/Course; Present Position; Course Intercept Requirements
	- 2 Acquire Altitude	Present Altitude; Required Altitude; Altitude Profile
	- 3 Acquire Speed	Present Speed; Required Speed; Speed Profile
OR 1.5.2 RETURN TO LOITER	-----Reference Functions/Actions for 1.1.1.5 Commence Loiter Operation	
OR 1.5.3 AWAIT NEXT RECEIVER CYCLE	-----Reference Functions/Actions as Relevant for 1.1.2 Acquire Tanker/Establish Intercept; 1.2 Perform Closure Operations	----- See References Also Consider: Refueling Mode Variations; Alternative Rendezvous Areas; Formation Receivers; Independent Receivers with Rendezvous Overlap; Independent Receivers with Staged Arrival; Receiver Variations

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